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ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

MISCELLANEOUS PAPERS.

1888—1895.

31.

CAMBRIDGE, MASS., U. S. A.
1896.

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INTRODUCTORY NOTE.

In the autumn of 1887, a list was printed of the titles of the minor publications of the officers of the Observatory during the preceding ten years. An asterisk prefixed to a title indicated that a number of extra copies were still available for presentation to such specialists as desired to make use of them. A number of copies were bound together and presented to the principal observatories and libraries of the world.

The list here printed forms a continuation of that just described, except that quarto publications, excluded in the first list, are included in the present list. No asterisks, however, have been prefixed to the titles of these quarto publications. In general, copies of them are still available for distribution. The Annals of the Observatory, or extracts from them, are not included in either list. The order of the papers is substantially that in which they are arranged in the lists given in the successive Annual Reports of the Observatory. In these Reports, the papers of each author published during any one year are named in immediate succession, and no attempt is made to preserve the exact chronological order of publication of papers by different authors appearing in the course of the same year.

Fifty copies of the collection of papers, the titles of which are marked by an asterisk, have been bound and separately numbered.

EDWARD C. PICKERING.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass, U. S. A., April 24, 1896.

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LIST OF TITLES.

Henry Draper Memorial. Second Annual Report of the Photographic Study of Stellar Spectra conducted at the Harvard College Observatory. EDWARD C. PICKERING, Director. With two Plates. (Cambridge, 1888. Reprinted in Nature, XXXVIII. 306, and Memorie della Società degli Spettroscopisti Italiani.)

Boyden Fund. Circular No. 3. Observations of Temperature and Rainfall.

Comet-Meteor Radiants. By O. C. WENDELL. (Astronomische Nachrichten, CXVIII. 175.)

Occultations observed during the Lunar Eclipse of January 28, 1888. By O. C. WENDELL. (Ibid., CXVIII. 309.)

Observations of Planet (80) Sappho. By O. C. WENDELL. (Ibid., CXIX. 299.)

Orbits of Meteors. By O. C. WENDELL. (Sidereal Messenger, VII. 37.)

Orbit of Comet 1888 *a* (Sawerthal). By O. C. WENDELL. (Ibid., VII. 216.)

The Apparent Instability of Stars near the Horizon (Sternschwanken). By ARTHUR SEARLE. (Astronomische Nachrichten, CXX. 109.)

*Forty-third Annual Report of the Astronomical Observatory of Harvard College. (Reprinted in part in The Observatory, XII. 111.)

Henry Draper Memorial. Third Annual Report of the Photographic Study of Stellar Spectra conducted at the Harvard College Observatory. EDWARD C. PICKERING, Director. (Cambridge, 1889. Reprinted in Nature, XL. 17.)

A Large Photographic Telescope.

Bruce Photographic Telescope.

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Beobachtungen des veränderlichen Sterns Z Sagittarii. By E. C. PICKERING. (Astronomische Nachrichten, CXXI. 188.)

Stars having Peculiar Spectra. By E. C. PICKERING. (Ibid., CXXII. 159.)

Photographic Chart of the Heavens. By E. C. PICKERING. (The Observatory, XII. 375.)

Atmospheric Economy of Solar Radiation. By ARTHUR SEARLE. (Proc. Am. Acad., XXIV. 26.)

Physical Aspect of the Planet Mars. By W. H. PICKERING. (Science, XII. 83.)

Soaring of Birds. By W. H. PICKERING. (Ibid., XIII. 31, 151, 245.)

Total Solar Eclipse of August, 1887. By W. H. PICKERING. (The Observatory, XII. 213.)

Determination of the Sensitiveness of Photographic Plates. By W. H. PICKERING. (International Annual of Anthony's Photographic Bulletin, II. 185.)

Total Solar Eclipse of January, 1889. By W. H. PICKERING. (Sidereal Messenger, VIII. 337.)

The Orion Nebula. By W. H. PICKERING. (Knowledge, XII. 191; XIII. 247.)

Ephemeris of Comet 1889 I. for January and February, 1889. By O. C. WENDELL. (Sidereal Messenger, VII. 82.)

Ephemeris of Comet 1889 I. for March, 1889. By O. C. WENDELL. (Ibid., VII. 132.)

Ephemeris of Comet 1889 I. for April, 1889. By O. C. WENDELL. (Ibid., VII. 225.)

Ephemeris of Comet 1889 II. for June, 1889. By O. C. WENDELL. (Ibid., VII. 266.)

Observations of Comet 1888 I. By O. C. WENDELL. (Astronomische Nachrichten, CXX. 235.)

Observations of Comet 1888 III. By O. C. WENDELL. (Astronomische Nachrichten, CXX. 251; Astronomical Journal, VIII. 135.)

Elements of Comet 1889 I. By O. C. WENDELL. (Astronomische Nachrichten, CXXI. 239.)

Observations of Comet 1889 II. By O. C. WENDELL. (Astronomische Nachrichten, CXXI. 319; Astronomical Journal, IX. 8.)

Observations of Comet 1889 *d*. By O. C. WENDELL. (Astronomische Nachrichten, CXXII. 217; Astronomical Journal, IX. 69.)

*Forty-fourth Annual Report of the Astronomical Observatory of Harvard College. (Cambridge, 1890.)

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Circular on Aid to Astronomical Research. By EDWARD C. PICKERING. (Reprinted in Nature, XLII. 299; The Observatory, XIII. 286; Sidereal Messenger, IX. 329.)

Observations of the Zodiacal Light made at Harvard College Observatory. By ARTHUR SEARLE. (Astronomische Nachrichten, CXXIV. 405.)

Comparison of Photographic Efficiency of Telescopes. By W. H. PICKERING. (Knowledge, XIII. 35.)

The Great Nebula in Orion. By W. H. PICKERING. (Sidereal Messenger, IX. 1.)

The Occultation of Jupiter, September 3, 1889. By W. H. PICKERING. (Ibid. IX. 148.)

Photographs of the Surface of Mars. By W. H. PICKERING. (Ibid., IX. 254.)

Visual Observation of the Surface of Mars. By W. H. PICKERING. (Ibid., IX. 369.)

Use of the Swing-back versus the Sliding-front. By W. H. PICKERING. (Anthony's International Photographic Annual, 1890, p. 252.)

Comets of 1887–88. By O. C. WENDELL. (Sidereal Messenger, IX. 38.)

Orbit of Comet 1890 I. By O. C. WENDELL. (Ibid., IX. 89.)

Observations of Comets 1887 V., 1888 V., and 1889 I. By O. C. WENDELL. (Astronomische Nachrichten, CXXIII. 295; Astronomical Journal, IX. 91.)

Transit of Comet 1889 V. over a Star. By O. C. WENDELL. (Sidereal Messenger, IX. 134.)

Observations of Comets 1889 VI. and 1890 I. By O. C. WENDELL. (Astronomische Nachrichten, CXXIV. 113; Astronomical Journal, IX. 159.)

An Approximate Solution of Euler's Equation for Parabolic Motion. By O. C. WENDELL. (Sidereal Messenger, IX. 176.)

Observations of Comet 1886 VII. By O. C. WENDELL. (Astronomische Nachrichten, CXXIV. 363; Astronomical Journal, IX. 191.)

Observations of Comets 1889 I., 1889 V., Companion to 1889 V., Comet *a* 1890, Comet *b* 1890, and Comet *c* 1890. By O. C. WENDELL. (Astronomical Journal, X. 69.)

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Ephemeris of Comet *a* 1890. By O. C. WENDELL. (Sidereal Messenger, IX. 276.)

Elements and Ephemeris of Comet *a* 1890. By O. C. WENDELL. (Ibid., IX. 324.)

Ephemeris of Comet *c* 1890, for October, 1890. By O. C. WENDELL. (Ibid., IX. 374.)

Spectra of δ and μ Centauri. By M. FLEMING. (Astronomische Nachrichten, CXXIII. 383; Sidereal Messenger, IX. 91.)

New Variable in Cælum. By M. FLEMING. (Astronomische Nachrichten, CXXIV. 175.)

Stars having Peculiar Spectra. By M. FLEMING. (Ibid., CXXV. 155.)

Two New Variable Stars near the Cluster 5 M Libræ. By M. FLEMING. (Ibid., CXXV. 157.)

New Variable Star in Scorpius. By M. FLEMING. (Ibid., CXXV., 361.)

Stars having Peculiar Spectra. By M. FLEMING. (Ibid., CXXV. 363.)

New Variable Star in Sagittarius. By M. FLEMING. (Ibid., CXXV. 365.)

Stars having Peculiar Spectra. By M. FLEMING. (Sidereal Messenger, IX. 379.)

Transit Observations in Photography. By W. P. GERRISH. (Ibid., IX. 121.)

A Simple Break Circuit for Clocks. By W. P. GERRISH. (Ibid., IX. 124.)

On the Spectrum of ζ Ursæ Majoris. By EDWARD C. PICKERING. (American Journal of Science, CXXXIX. 46. Reprinted in The Observatory, XIII. 80; Sidereal Messenger, IX. 80.)

New Variable Star in Cygnus. By EDWARD C. PICKERING. (Sidereal Messenger, IX. 232.)

Sur les Résultats Photométriques auxquels peut conduire la Photographie Céleste. By EDWARD C. PICKERING. (Bulletin du Comité International Permanent pour l'Exécution photographique de la Carte du Ciel, Cinquième Fascicule, p. 350. Paris, 1890.)

Letter to Admiral Mouchez. By EDWARD C. PICKERING. (Ibid., p. 371.)

A New Class of Binary Stars. By EDWARD C. PICKERING. (Monthly Notices of the Royal Astronomical Society, L. 296.)

Southern Stars having Peculiar Spectra. By EDWARD C. PICKERING. (Astronomische Nachrichten, CXXIII. 95.)

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Spectrum of Pleione. By EDWARD C. PICKERING. (Astronomische Nachrichten, CXXIII. 95.)

Variable Stars in Cluster G. C. 3636. By EDWARD C. PICKERING. (Ibid., CXXIII. 207.)

The Star $12^h\ 18.0^m\ -48°\ 43'$ (1875.0). By EDWARD C. PICKERING. (Ibid., CXXIV. 21.)

New Variable Star in Cygnus, DM. $+48°$ 2942. By EDWARD C. PICKERING. (Ibid., CXXIV. 271.)

*A history of the Observatory from its foundation to the present time was recently published by Mr. Daniel W. Baker, of Boston, in a series of articles in the Boston Evening Traveller, and has been reprinted in pamphlet form.

By the kind assistance of Hon. Patrick Egan, United States Minister to Chili, a full description of the work of the Observatory in South America, prepared by Mr. M. H. Bailey, was published at Santiago on February 19, 1890, in El Ferrocarril, and at Valparaiso on the following day in El Mercurio.

*Forty-fifth Annual Report of the Astronomical Observatory of Harvard College. (Cambridge, 1890).

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Harvard College Observatory. (A circular inviting subscriptions for the new fire-proof building.)

A Possible Secondary Cause of the Phenomenon of Gegenschein. By ARTHUR SEARLE. (Astronomische Nachrichten, CXXVI. 115.)

Observations of Comets 1889 I., 1889 V., Companion to 1889 V., Comet 1890 II., 1890 III., 1890 VI. By O. C. WENDELL. (Ibid., CXXVI. 43.)

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Second Series of Observations of Comet 1890 IV. By O. C. WENDELL. (Astronomische Nachrichten, CXXVII. 297; Astronomical Journal, X. 123.)

Observations of Comet 1882 II. By O. C. WENDELL. (Astronomische Nachrichten, CXXVII. 293.)

Observations of Comet 1889 I., Comet 1890 II., Comet 1890 III., Comet 1890 VI., and Comet a 1891. By O. C. WENDELL. (Astronomische Nachrichten, CXXVII. 297; Astronomical Journal, XI. 4.)

Ephemeris of Comet 1890 VI., for November, 1890. By O. C. WENDELL. (Sidereal Messenger, IX. 419.)

Ephemeris of Comet 1890 II., for December, 1890. By O. C. WENDELL. (Ibid., IX. 465.)

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Ephemeris of Comet 1890 IV., for February, 1891. By O. C. WENDELL. (Ibid., X. 102.)

Ephemeris of Comet 1890 II., for March, 1891. By O. C. WENDELL. (Ibid., X. 147.)

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Orbit and Ephemeris of Comet *a* 1891. By O. C. WENDELL. (Ibid., X. 288.)

Ephemeris of Comet *a* 1891, for July, 1891. By O. C. WENDELL. (Ibid., X. 368.)

Stars having Peculiar Spectra, including New Variable Stars in Triangulum and Hydra. By M. FLEMING. (Astronomische Nachrichten, CXXVI. 117.)

Stars having Peculiar Spectra. By M. ELEMING. (Ibid., CXXVI. 165.)

Stars having Peculiar Spectra. New Variable Stars in Perseus, Triangulum, and Hydra. By M. FLEMING. (Sidereal Messenger, X. 7.)

Astronomical Expedition to Peru. By M. FLEMING. (Ibid., X. 105.)

Stars having Peculiar Spectra. New Variables in Aquarius and Delphinus. By M. FLEMING. (Ibid., X. 106.)

New Variable Star in Camelopardalis. By M. FLEMING. (Ibid., X. 152.)

The New Red Star in Auriga. By M. FLEMING. (English Mechanic, LIII. 50.)

Objects of Interest on Spectrum Plates and Two New Variable Stars in Perseus. By M. FLEMING. (Astronomische Nachrichten, CXXVI. 163.)

Stars having Peculiar Spectra. New Variable Stars in Aquarius, Delphinus, and Camelopardalis. By M. FLEMING. (Ibid., CXXVII. 5.)

New Planetary Nebula. DM. —12° 1172. By M. FLEMING. (Sidereal Messenger, X. 240.)

Stars having Peculiar Spectra. New Variable Star in Sagittarius, R. A. 19^h 51.8^m, Dec. —42° 7′. By M. FLEMING. (Astronomische Nachrichten, CXXVIII. 11.)

Stars having Peculiar Spectra. New Variable Star in Lacerta. DM. +39° 4851. By M. FLEMING. (Ibid., CXXVIII. 121.)

Aid to Astronomical Research. By EDWARD C. PICKERING. (Reprinted in Sidereal Messenger, IX. 473.)

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Close Binary Stars. By EDWARD C. PICKERING. (Sidereal Messenger, X. 5.)

A Fifth Type of Stellar Spectra. By EDWARD C. PICKERING. (Astronomische Nachrichten, CXXVII. 1.)

The Discovery of Double Stars by Means of their Spectra. By EDWARD C. PICKERING. (Ibid., CXXVII. 155.)

Spectrum of β Lyræ. By EDWARD C. PICKERING. (Ibid., CXXVIII. 39. Reprinted in The Observatory, XIV. 341.)

The Draper Catalogue. By EDWARD C. PICKERING. (Nature, XLIV. 223.)

*Forty-sixth Annual Report of the Director of the Astronomical Observatory of Harvard College. (Cambridge, 1891.)

A Large Southern Telescope. (Circular describing the Advantages of establishing such an instrument at Arequipa, Peru.)

Astronomical Possibilities at considerable Altitudes. By W. H. PICKERING. (Astronomische Nachrichten, CXXIX. 97. Reprinted in The Observatory, XV. 283.)

An Investigation of the Systems of Bright Streaks visible upon the Full Moon. By W. H. PICKERING. (Astronomische Nachrichten, CXXX. 225.)

Are there at present Active Volcanoes upon the Moon? By W. H. PICKERING. (The Observatory, XV. 250.)

The Mountain Station of the Harvard College Observatory. By W. H. PICKERING. (Astronomy and Astro-Physics, XI. 353.)

The Boyden Station of the Harvard College Observatory. By W. H. PICKERING. (Ibid., XI. 357.)

Colors exhibited by the Planet Mars. By W. H. PICKERING. (Ibid., XI. 449.)

The Earthquake for February 23, 1892. By W. H. PICKERING. (Ibid., XI. 470.)

Colors exhibited by the Planet Mars. By W. H. PICKERING. (Ibid., XI. 545.)

The Planet Saturn and its Satellites. By W. H. PICKERING. (Idid., XI. 649.)

Mars. By W. H. PICKERING. (Ibid., XI. 668.)

The Glacial Period and the Planet Mars. By W. H. PICKERING. (Knowledge, XV. 113.)

Can a Planet absorb its Oceans without having its Surface Temperature lowered? By W. H. PICKERING. (Ibid., XV. 193.)

Observations of Comet 1891 V. By O. C. WENDELL. (Astronomical Journal, XI. 56.)

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Orbit of Comet 1891 IV. By O. C. WENDELL. (Astronomy and Astro-Physics, XI. 87.)

Ephemeris of Comet 1891 IV., for March. By O. C. WENDELL. (Ibid., XI. 251.)

Observations of Comet *a* 1892. By O. C. WENDELL. (Astronomical Journal, XI. 158.)

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Observations of Comets 1891 II. and 1891 V. By O. C. WENDELL. (Astronomische Nachrichten, CXXX. 45; Astronomical Journal, XI. 191.)

Observations of Comets *a* 1892 and *c* 1892. By O. C. WENDELL. (Astronomical Journal, XI. 191.)

Second Orbit of Comet *a* 1892. By O. C. WENDELL. (Astronomy and Astro-Physics, XI. 536.)

Ephemeris of Comet *a* 1892 for August. By O. C. WENDELL. (Ibid., XI. 625.)

Second Series of Observations of Comet *a* 1892. Also Observations of Comet *c* 1892. By O. C. WENDELL. (Astronomical Journal, XII. 94.)

New Variable Stars in the Southern Sky. By M. FLEMING. (Astronomische Nachrichten, CXXX. 125.)

*Stars having Peculiar Spectra. By M. FLEMING. (Astronomy and Astro-Physics, XI. 418.)

Astronomical Expedition to Peru. By M. FLEMING. (Publications of the Astronomical Society of the Pacific, No. 22, p. 58.)

Distribution of Energy in Stellar Spectra. By EDWARD C. PICKERING. (Astronomische Nachrichten, CXXVIII. 377. Reprinted in Astronomy and Astro-Physics, XI. 22.)

On the New Star in Auriga. By EDWARD C. PICKERING. (Astronomische Nachrichten, CXXIX. 111.)

A New Variable Star in Aries. By EDWARD C. PICKERING. (Ibid., CXXXI. 62.)

*The Objective Prism. By EDWARD C. PICKERING. (Astronomy and Astro-Physics, XI. 199.)

*The New Star in Auriga. By EDWARD C. PICKERING. (Ibid., XI. 228.)

A Change in the Spectrum of Nova Aurigæ. By EDWARD C. PICKERING. (Ibid., XI. 330.)

*Nova Aurigæ. By EDWARD C. PICKERING. (Ibid., XI.) 417.

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Nova Aurigæ. By EDWARD C. PICKERING. (Astronomy and Astro-Physics, XI. 750.)

A New Variable Star. By EDWARD C. PICKERING. (Ibid., XI. 752.)

*Forty-seventh Annual Report of the Director of the Astronomical Observatory of Harvard College. (Cambridge, 1892.)

A Large Southern Telescope. (Circular issued last year and reprinted in Astronomy and Astro-Physics, XI. 783.)

*Publications and Photographic Illustrations issued by the Observatory of Harvard College. (Cambridge, 1893.)

*The Astronomical Observatory of Harvard College. (Circular describing the stations, instruments, and publications of the Observatory. Cambridge, 1893.)

Improved Methods of Observing the Zodiacal Light. By ARTHUR SEARLE. (Astronomische Nachrichten, CXXXII. 163.)

Lunar Atmosphere and the Recent Occultation of Jupiter. By W. H. PICKERING. (Astronomy and Astro-Physics, XI. 778.)

Mars. By W. H. PICKERING. (Ibid., XI. 849.)

*The Planet Jupiter and its Satellites. By W. H. PICKERING. (Ibid., XII. 193.)

Jupiter's Satellites. By W. H. PICKERING. (Ibid., XII. 390.)

The Rotation of Jupiter's Outer Satellites. By W. H. PICKERING. (Ibid., XII. 481.)

Polar Inversions of the Planets and Satellites. By W. H. PICKERING. (Ibid., XII. 692.)

Plato. By W. H. PICKERING. (The Observatory, XVI. 175.)

El Planeta Saturno y sus Satélites. W. H. PICKERING. (La Gaceta Cientifica, Publicacion mensual de la Sociedad "Amantes de la Ciéncia," [Lima, Peru,] Año IX. pp. 25–28.)

* ω Centauri. By SOLON I. BAILEY. (Astronomy and Astro-Physics, XII. 689.)

Observations of Comet 1893 I. By O. C. WENDELL. (Astronomische Nachrichten, CXXXI. 167.)

Observations of Comet 1892 III. By O. C. WENDELL. (Astronomical Journal, XII. 119.)

Observations of Comet *g* 1892. By O. C. WENDELL. (Ibid., XII. 128.)

Second Series of Observations on Comets *f* and *g* 1892. By O. C. WENDELL. (Ibid., XII. 142.)

Ephemeris of Comet 1892 VI. By O. C. WENDELL. (Astronomy and Astro-Physics, XII. 85.)

Observations of Comets *a*, *d*, *e*, and *f* 1892. By O. C. WENDELL. (Astronomical Journal, XII. 157.)

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Note on Comet 1893 II. By O. C. WENDELL. (Astronomy and Astro-Physics, XII. 660.)

*Stars having Peculiar Spectra. By M. FLEMING. (Ibid., XI. 765.)

*Stars having Peculiar Spectra. By M. FLEMING. (Ibid., XII. 170.)

*Stars having Peculiar Spectra. By M. FLEMING. (Ibid., XII. 546.)

A Field for Woman's Work in Astronomy. By M. FLEMING. (Ibid., XII. 683.)

Stars that have been found Variable in the Photograph. By W. M. REED. (Astronomical Journal, XIII. 62.)

Swift's Comet. By A. E. DOUGLASS. (Astronomy and Astro-Physics, XII. 202.)

The Balance Roof for Telescope Buildings. By A. E. DOUGLASS. (Ibid., XII. 207.)

Indications of a Rainy Period in Southern Peru. By A. E. DOUGLASS. (Science, XX. 231.)

A Useful Bath. By A. E. DOUGLASS. (Anthony's Photographic Bulletin, XXIII. 654.)

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*Work for Large Telescopes. By E. C. PICKERING. (Ibid., XII. 114.)

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New Variable Star in Carina. By E. C. PICKERING. (Astronomical Journal, XIII. 79.)

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*Telescope Mountings and Domes. By W. H. PICKERING. (Ibid., XIII. 1. Reprinted in The Observatory, XVII. 73.)

*A Study of Nova Aurigæ and Nova Normæ. By W. H. PICKERING. (Ibid., XIII. 201.)

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A Convenient Naked-Eye Star Atlas. By O. C. WENDELL. (Popular Astronomy, II. 47.)

*Stars having Peculiar Spectra. By M. FLEMING. (Astronomy and Astro-Physics, XII. 810.)

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The New Star in Norma. By E. C. PICKERING. (Ibid., XIII. 398.)

*Photographic Determination of Stellar Motions. By E. C. PICKERING. (Ibid., XIII. 521.)

The Astronomical Observatory. By E. C. PICKERING. (Harvard Graduates Magazine, II. 241.)

The Astronomical Observatory. By E. C. PICKERING. (Ibid., II. 394.)

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*Forty-ninth Annual Report of the Director of the Astronomical Observatory of Harvard College. (Cambridge, 1894.)

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The Harvard College Meteorological Stations in Peru. By S. I. BAILEY. (American Meteorological Journal, XI. 76.)

Stars having Peculiar Spectra. By M. FLEMING. (Astronomische Nachrichten, CXXXVII. 71.)

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Comparison of Photometric Magnitudes of the Stars. By E. C. PICKERING. (Astronomische Nachrichten, CXXXVII. 65.)

Observations of the Transit of Mercury, 1894, November 10. By E. C. PICKERING. (Ibid., CXXXVII. 69.)

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*Comparison of Photometric Magnitudes of the Stars. By E. C. PICKERING. (Ibid., I. 154.)

*T Andromedæ. By E. C. PICKERING. (Ibid., I. 305.)

*Eclipse of Jupiter's Fourth Satellite, February 19, 1895. By E. C. PICKERING. (Ibid., I. 309.)

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*A New Form of Stellar Photometer. By E. C. PICKERING. (Astrophysical Journal, II. 89.)

*Fiftieth Annual Report of the Director of the Astronomical Observatory of Harvard College. (Cambridge, 1895.)

*Seven New Variable Stars. By M. FLEMING. (Astrophysical Journal, II. 198.)

*Stars having Peculiar Spectra. By M. FLEMING. (Ibid., II. 354.)

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Circular No. 2. Variable Star Clusters. November 2, 1895.

Circular No. 3. New Variable Star of the Algol Type. December 13, 1895.,

Circular No. 4. A New Star in Centaurus. The New Algol Variable in Delphinus. December 20, 1895.

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FORTY-THIRD

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

BY

EDWARD C. PICKERING.

PRESENTED TO THE VISITING COMMITTEE DECEMBER 15, 1888.

CAMBRIDGE, MASS.
PUBLISHED BY THE UNIVERSITY.
1888.

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REPORT.

To the President of the University:

Sir, — The Observatory has suffered a severe loss by the death of one of its oldest friends, the last survivor of those who took an earnest part in its establishment. The active aid rendered by Mr. J. I. Bowditch in every attempt to extend our work, during the entire career of the Observatory, has done much to bring it to its present condition.

A gift of fifty thousand dollars was received last summer from Miss C. W. Bruce of New York, for the construction of a photographic telescope of novel form. The importance of this gift will be explained below. If successful, it will materially affect the entire plan of work of this Observatory.

By the continued aid of Mrs. Draper, with that of the Boyden Fund, an expedition has been sent to Peru, and will thus enable some of the most important investigations made here to be extended so as to include the southern stars. The plan of maintaining two stations, one in the northern hemisphere and one in the southern, will permit all our researches to include the entire sky, and thus give them a completenesss unattainable at any single station. A second expedition to southern California gives us a mountain station under climatic conditions much superior to those of the eastern portion of the United States, and promises to be a satisfactory solution of the problem contemplated by Mr. Boyden in his will. All of these plans greatly increase the work accomplished by the Observatory and also its expenditures. Notwithstanding the large addition to its resources, the entire income has been expended in almost all of its departments. The institution is therefore much larger, but cannot be regarded as richer in the sense of being able to indulge in luxuries, or even to supply some obvious needs. The increased amount of work renders more urgent certain wants of the Observatory which have been pointed out in past years. The most important of these is a new fire-proof building. More room is constantly required, but no funds are available for this purpose. In order to replace the records and other property now contained in the main building, which might easily be destroyed in a few minutes by fire, the sum of at least one hundred thousand dollars would be required.

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Should such a calamity occur, the Director feels that he should not be held responsible, after pointing out this danger year after year. In at least one case a large gift to the Observatory was imperilled when the donor learned of the danger from fire. A gift of ten or even of five thousand dollars would partially remedy this difficulty by permitting the erection of a small brick building in which the photographs and manuscripts could be safely stored. Such a building would form a part of the large structure which will be imperatively needed in the near future. If the income of the Observatory is expended for this purpose, a corresponding part of the work described below must be abandoned or so much delayed as greatly to diminish its value.

Publication of results is the only certain way to secure observations permanently from destruction. This work is now being vigorously pursued. During a large part of the year as many as five volumes of Annals have been simultaneously in course of publication.

Observatory Instruments.

East Equatorial. — This instrument has been provided with six new eyepieces, and two square bar micrometers made of tinfoil mounted upon glass by Professor Rogers. The observations made during the year are as follows: 22 eclipses of Jupiter's satellites have been photometrically observed, making in all 430 since 1877; the comparison stars of S *Cephei* were observed on one night with the wedge photometer; this photometer has also been used in the observation of three asteroids, (4) Vesta on 13 dates, (7) Iris on 23, and (1) Ceres on 16; and in the observation on 30 dates of zones of stars from the Durchmusterung. The following comets have been observed for position: 1888 V. on 8 dates; 1889 I. on 17; 1889 II. on 4; and the comet discovered by Brooks on July 6, on 10 dates. Companion *c* to the comet last mentioned was observed on 2 dates. At the request of the discoverer, the asteroid (287) Nephthys, found by Professor Peters, was observed on 3 nights. Since February 25, 1889, each of 16 circumpolar variable stars has been observed about once in two weeks by Argelander's method and by estimate; the total number of these observations is 206. There are also 11 series of observations of the comparison stars of these variables, made with the wedge photometer and by estimate. A new variable discovered by Peters has been observed photometrically 5 times, and 7 observations were made by Argelander's method of a variable discovered by photographic means in the cluster G. C. 3636. These observations, except those of Jupiter's satellites, have been made by Mr. Wendell.

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Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision. The catalogue of the zone from 50° to 55° of north declination is completed and the first half of it has been forwarded, ready for printing, to the Astronomische Gesellschaft. The second half will soon be sent. The discussion of the systematic errors of the various catalogues which contain stars between the declinations +49° 50′ and +55° 10′ has also been finished and tables have been prepared for the reduction of these catalogues to the system of the Astronomische Gesellschaft. The entire discussion of the proper motions will soon be ready for publication. It will occupy about 200 printed pages. Less progress has been made in the reduction of the observations made from 1879 to 1883, as this work has been considered less urgent than that on the zone observations just mentioned.

The observation of the southern zone comprising the declination from —9° 50′ to —14° 10′ has been continued through the year by Professor Searle, assisted by Mr. Dunne. The number of nights of observation is 143; the total number of observations is 8565, distributed as follows: 287 relating to circumpolar stars, 1024 to fundamental stars, 6889 to zone stars, and 365 to stars incidentally observed, more particularly to a series of comparison stars for the asteroid (12) Victoria, observed at the request of Dr. Gill. Continuous progress has been made in the reductions, which cannot, however, be prevented, with the present force of computers, from falling considerably behind the observations, in the manner well known to be customary, and perhaps inevitable, in undertakings of this kind.

Horizontal Telescope. — The twelve-inch horizontal telescope described in the last report was completed so that it was ready for measuring the light of all stars brighter than the fourteenth magnitude. The pressure of other work, however, prevented regular observations from being undertaken with it. It is now being used by Mr. G. E. Hale in an investigation on the solar spectrum.

Henry Draper Memorial.

The first research on the spectrum of over ten thousand of the brighter stars is now nearly completed and is partially in print. The photographs required for the second research on the spectrum of the fainter stars are also nearly complete. The eleven-inch telescope has been in constant use throughout nearly every clear night in photographing the spectrum of the brighter stars. This work is approaching completion for all stars bright enough to be photographed by means of our present appliances, with the large dispersion now employed.

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Good progress has also been made with the classification of the spectra, and the study of the slight differences in different stars. By the use of an improved process for staining plates with erythrosin, the yellow and green portions of the spectrum, even of the fainter stars, can be advantageously studied. Numerous experiments have been made with a device for measuring the approach and recession of stars, by means of an achromatic prism in front of the object-glass. Several peculiar spectra have been studied, especially that of ζ Ursae Majoris. The periodic doubling of its lines seems to be due to the rotation of two components too close to be distinguished by direct observation. The detection of bright lines in one of the stars in the Pleiades suggests a possible explanation of the legend that seven stars were formerly visible in this group.

During last spring an expedition was sent to Peru in charge of Mr. S. I. Bailey, assisted by Mr. M. H. Bailey. A station was selected on a mountain about six thousand feet high and about eight miles from Chosica. All supplies for the station, including water, must be carried by mules for this distance. Two frame buildings covered with paper have been erected, one for an observatory, the other for a dwelling house. Since May 9 the Bache telescope has been kept at work during the whole of every clear night. 1236 photographs have been obtained. The plan proposed will cover the sky south of —15° four times, once with photographs of spectra having an exposure of an hour which will include stars to about the eighth magnitude; secondly, with an exposure of ten minutes giving the brighter stars; thirdly, with charts having an exposure of one hour, permitting a map of the southern stars to the fourteenth magnitude inclusive; and fourthly, with charts having an exposure of ten minutes, including stars to about the tenth magnitude. The weather for the first four or five months was excellent, being clear nearly every evening. Fogs and cloud which often covered the adjacent valleys and the city of Lima did not reach to the top of the mountain. The cloudy season is now beginning and the work will be more interrupted. But nearly one half of the entire programme has already been carried out. A large number of interesting objects have been detected, among others several stars having bright lines in their spectra. Including the photometric work described below, the amount of material so far collected is unexpectedly large.

Boyden Fund.

The climate of southern California seems especially favorable to the undertaking desired by Mr. Boyden. An expedition under the direction of Professor William H. Pickering was accordingly sent in

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November, 1888, to the summit of Wilson's Peak, in the vicinity of Los Angeles. In order that as much useful work as possible might be accomplished, the thirteen-inch telescope and the eight-inch telescope now in Peru were sent to Willows, California, where the Total Solar Eclipse of January 1, 1889, was successfully observed. Forty-seven photographs were obtained by the party during the three minutes of totality, and the instrumental equipment was much superior to any previously used for such a purpose. It was not until May 11, that the large telescope was successfully mounted on Wilson's Peak, by Messrs. E. S. King and Robert Black, but since then it has been kept at work throughout every clear night. The number of photographs obtained is 1155. The objects photographed are selected from a list of 625 double stars, 143 clusters and other celestial bodies, such as the Moon and planets. As these same objects have been repeatedly photographed at Cambridge with the same instrument, an accurate comparison of the atmospheric conditions of the two places may be made. It will of course be impossible to derive a final conclusion until the observations have extended over at least a year, but the evidence already secured shows that in summer results can be obtained at Wilson's Peak which cannot be obtained here. The difference is very pronounced for such objects as the markings on Jupiter. Clusters like that in Hercules are well resolved, so that the individual stars are easily measured, which cannot be done with the best Cambridge photographs. As a test-object the sixth star in the trapezium of the Orion nebula is clearly photographed for the first time. A new variable star has been discovered in the midst of the cluster G. C. 3636. A beginning has been made of the measurements of the position and brightness of the double stars, and it is hoped to extend this work to the clusters, and thus furnish an extensive addition to this department of micrometric astronomy.

Much experimental work has also been done at Cambridge, as is shown by the fact that nearly a thousand photographs have also been taken there. Moreover, the expedition to Peru is largely supported by the Boyden Fund. The meridian photometer will be used to extend two large series of observations to the south pole. These are the Harvard Photometry, and the zones used in the revision of the Durchmusterung. This work will furnish photometric magnitudes of stars as bright as the ninth magnitude in all parts of the sky. The Messrs. Bailey have observed 67 series, one of them including 293 stars. In all, during less than six months, about 6700 stars have been observed, which have required 26,800 settings.

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The Bruce Photographic Telescope.

For the last six years experiments have been in progress here on the use of a photographic doublet in the preparation of maps of the stars. The eight-inch telescope now in Peru is of this form and was mounted here in 1885. Since then 4500 photographs have been taken with it. With an exposure of an hour twice as many stars can be photographed as are visible with a telescope having an aperture of fifteen inches, and as many stars as can be photographed in the same time with a telescope of the usual form having an aperture of thirteen inches. Moreover with a doublet a portion of the sky covering twenty-five square degrees can be photographed with good definition, while only three or four degrees can be covered equally well with telescopes of the usual form. The time required to photograph the entire sky will be reduced in the same proportion. With a doublet each hemisphere could be covered in one year with eight hundred plates. In 1885 it was proposed to photograph the entire sky with the eight-inch telescope, enlarging the plates three times. The results would resemble in scale and size the charts of Peters and Chacornac. The generous aid of Miss Bruce mentioned above will permit this result to be attained in the original photographs, without enlargement. A contract has been made with Messrs. Alvan Clark & Sons for a telescope having an aperture of twenty-four inches and a focal length of eleven feet. Meanwhile nineteen foreign observatories have united in an Astrophotographic Congress to prepare a map of the stars to the fourteenth magnitude with telescopes of the usual form having apertures of thirteen inches. The plans have been matured with great care and skill. The courteous reference to the Bruce Telescope and its proposed work by Admiral Mouchez shows that both plans can be carried out without disadvantageous duplication. Doubtless each plan will possess certain advantages over the other. The Bruce telescope will be especially adapted to studying the very faint stars. It is hoped that those of the sixteenth magnitude and fainter can be photographed. Its principal use will probably be for the study of the distribution of the stars, for complete catalogues of clusters, nebulae, and double stars and for the spectra of faint stars. The amount of material accumulated will be enormous and the best method of discussion will form a very difficult and important problem.

Miscellaneous.

Library.—The library of the Observatory has been increased during this year by the addition of 484 volumes and 336 pamphlets. The relatively small increase in pamphlets is explained by the fact that

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large numbers of pamphlets have been bound in volumes. An actual count of the works contained in the library on November 1, 1889, showed the total numbers of volumes and pamphlets to be respectively 6456 and 6125. The corresponding numbers found by adding the increase above stated to the totals given in the report of the University Librarian for last year are 4583 and 7911.

Time Service. — The standard time signals were sent by the Ballou clock No. 103 until August 21, since which date they have been sent by the Bond clock No. 394. No. 103 was then used as the normal clock while the sidereal clock, Frodsham No. 1327, commonly depended on for that service, was cleaned, and while the amount of mercury in the pendulum of No. 1327 was altered to secure better compensation for temperature. The average amount of the error of the time signals at the time of observing star transits has been 0^s.32; the average interval between the times of these determinations being 2.9 days. The average error of the signals at 10 A.M. has been 0^s.27, the number of clock comparisons taken for the purpose of keeping the error of the signals small being about 520. The average change in the daily rate from each day to the next has been 0^s.23.

The Boston Time-Ball was dropped at noon on 290 week days, 287 times automatically by telegraph. When the telegraphic communication is known to be faulty, the ball is not hoisted at all; but three times such faults started the ball prematurely. Each time it was quickly caught and held by the hand-brake until the proper moment for release. Once it was dropped five minutes early, but immediately rehoisted and dropped again at the proper time.

Telegraphic Announcements. — The telegraphic distribution of astronomical intelligence has been continued during the year under the management of Mr. Ritchie. Announcements have been made of the discovery of seven asteroids, six comets, a suspected change in the crater Plinius, the light of Saturn's rings, and the separation of comet Brooks. Thirteen cable messages have been received, and seven have been despatched, while the distribution in this country has been effected by telegrams in number as follows: asteroids, 81; comets, 293; and other notices, 19.

Publications. — A considerable number of Volumes of the Annals of the Observatory have been carried to a greater or less extent through the various stages of publication. It has already been mentioned that the Catalogue of the zone from the declination of +49° 50′ to that of +55° 10′, which will form Volume XV., Part II., has been completed and sent to Germany for publication. Of Volume XVIII., Nos. VI., VII., VIII. and IX. have appeared during the

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year. Their subjects are as follows: Detection of New Nebulae by Photography; A Photographic Determination of the Brightness of the Stars; Index to Observations of Variable Stars; Meridian Circle Observations of Close Polar Stars. A subsequent memoir will form No. X., and will complete the volume. Volume XIX., Part I., was published during the year. It contains a summary of the meteorological observations made at the Observatory from its foundation to to the end of 1888. Volume XX., Parts I. and II., has also been published. It contains the meteorological observations made during 1887 and 1888 at the Blue Hill Observatory, and has been prepared pursuant to the system of co-operation with that institution described in the last report. Volume XXI., Part I., contains the observations collected by the New England Meteorological Society, between which and this Observatory a similar system of co-operation exists. This volume is in type and nearly ready for printing. Volume XXII. requires only the final corrections before it is printed. It contains the observations made on Pike's Peak by the United States Signal Service from 1874 to 1888 inclusive, and is published in conformity with the agreement mentioned in the last report. Volume XXIII. will contain the description of the meridian photometer used from 1882 to 1888, and a discussion of its work. Of this volume 13 pages are in type. Volume XXIV. contains the results obtained with this photometer from the zones of stars from the Durchmusterung, which formed the principal subject of its work, as well as a catalogue of about 4000 other stars. Of this volume 146 pages are in type. Volume XXV. has not yet been undertaken. Volume XXVI. contains the description and discussion of the photographic work first undertaken to carry out the objects of the Henry Draper Memorial, and its first chapter, comprising 8 pages, is in type. Volume XXVII. contains the catalogue of magnitudes and spectra of stars described above as a portion of the Henry Draper Memorial. Proof of this has been received from the printers as far as page 109.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-third Annual Report of the Astronomical Observatory of Harvard College. Reprinted in part in the Observatory. xii. 111.

Henry Draper Memorial. Third Annual Report of the Photographic Study of Stella Spectra conducted at the Harvard College Observatory. Edwin C. Pickering, Director. Cambridge, 1889. Reprinted in Nature, xl. 17.

A Large Photographic Telescope.

Bruce Photographic Telescope.

Beobachtungen des veränderlichen Sterns Z Sagittarii. By E. C. Pickering. Astronomische Nachrichten, cxxi. 188.

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Stars having Peculiar Spectra. By E. C. Pickering. Ibid. cxxii. 159.

Photographic Chart of the Heavens. By E. C. Pickering. The Observatory, xii. 375.

Atmospheric Economy of Solar Radiation. By Arthur Searle. Proc. Am. Acad. xxiv. 26.

Physical Aspect of the Planet Mars. By W. H. Pickering. Science, xii. 83.

Soaring of Birds. By W. H. Pickering. Ibid. xiii. 31, 151, 245.

Total Solar Eclipse of Aug. 1887. By W. H. Pickering. The Observatory, xii. 213.

Determination of the Sensitiveness of Photographic Plates. By W. H. Pickering. International Annual of Anthony's Photographic Bulletin, ii. 185.

Total Solar Eclipse of Jan. 1889. By W. H. Pickering. Sidereal Messenger, viii. 337.

The Orion Nebula. By W. H. Pickering. Knowledge, xii. 191; xiii. 247.

Ephemeris of Comet 1889 I. for Jan. and Feb. 1889. By O. C. Wendell. Sidereal Messenger, vii. 82.

Ephemeris of Comet 1889 I. for March, 1889. By O. C. Wendell. Sidereal Messenger, vii. 132.

Ephemeris of Comet 1889 I. for April, 1889. By O. C. Wendell. Sidereal Messenger, vii. 225.

Ephemeris of Comet 1889 II. for June, 1889. By O. C. Wendell. Sidereal Messenger, vii. 266.

Observations of Comet 1888 I. By O. C. Wendell. Astronomische Nachrichten, cxx. 235.

Observations of Comet 1888 III. By O. C. Wendell. Astronomische Nachrichten, cxx. 251; Astronomical Journal, viii. 135.

Elements of Comet 1889 I. By O. C. Wendell. Astronomische Nachrichten, cxxi. 239.

Observations of Comet 1889 II. By O. C. Wendell. Astronomische Nachrichten, cxxi. 319; also, Astronomical Journal, ix. 8.

Observations of Comet 1889 d. By O. C. Wendell. Astronomische Nachrichten, cxxii. 217; also, Astronomical Journal, ix. 69.

EDWARD C. PICKERING, *Director.*

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HISTORY

OF THE

HARVARD COLLEGE OBSERVATORY

DURING THE PERIOD 1840–1890.

BY

DANIEL W. BAKER.

Reprinted from the Boston Evening Traveller.

CAMBRIDGE.
1890.

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PREFACE.

A CAREFUL study of the early history of the Harvard College Observatory has been made by Mr. DANIEL W. BAKER. Many facts were thus brought to light which had not appeared in print. A series of newspaper articles was accordingly prepared, which were published in the Boston "Evening Traveller" on six successive Saturdays, beginning August 2, 1890. Much of this material appearing to be of sufficient value for preservation in a more permanent form, it has been reprinted in the present pamphlet, with slight alterations, and with the addition of the illustrations given on page 25. The parts numbered IV. and V. originally appeared together as a single article. Reproductions have been made of some of the illustrations. The articles were originally addressed, not to professional astronomers, but to the general public, and are to be regarded as a popular description of the work accomplished at the Harvard College Observatory during the first fifty years of its existence.

EDWARD C. PICKERING.

HARVARD COLLEGE OBSERVATORY,
September 13, 1890.

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HISTORY

OF

THE HARVARD COLLEGE OBSERVATORY.

1840-1890.

THE present is the semi-centennial year of the Harvard College Observatory. A precise date cannot be named for the beginning, but in the early months of the year 1840 the institution was gradually organized, and before midsummer became a tangible fact and a working adjunct of the college.

While the first astronomical observation is of record Dec. 31, 1839, it is well known that the observatory had not then an official staff, the appointment of the first director being of date Feb. 12, 1840, and the confirmation by the Board of Overseers somewhat later. Moreover, this particular observation and others immediately following were made in continuation of work begun elsewhere and not identified with the college affairs.

The advance made in astronomical science during the 50 years past is among the wonderful facts comprised in the record of the 19th century, and it is true that since it became fairly organized and equipped, Harvard College Observatory has been in the front rank in the march. A review of this progress so far as pertaining to the institution at Cambridge, is, therefore, timely. A history of 50 years, embodying so many facts of the first importance and interest as does this, cannot, even with the most resolute purpose as respects brevity, be disposed of in a single chapter. This, accordingly, will be the first of a series. The reader may be assured at the outset that the topics to be touched upon are various and in themselves attractive, and that, so far as possible, technicalities will be shunned.

Regarding the period of beginning just referred to as the blossoming, whence has followed abundant fruitage, it may be remarked that a long time passed between the budding and the blossoming, and that indications of the flow of a vital current are recognizable at as remote a date as 1761. In that year the sloop owned by the province of Massachusetts was fitted out at public cost to convey Prof. John Winthrop and others connected with the college, provided with instruments belonging to the college, to Newfoundland, for observation of a transit of Venus. In 1780, notwithstanding the financial straits incident to the war, the commonwealth provided a small vessel of war, called a "galley," to take Prof. Samuel Williams, of the college, and party to Penobscot to observe a total eclipse of the sun. The first definite record pointing to a college observatory is of date 1805, when John Lowell, the uncle of that John Lowell who founded the Lowell Institute, being in Paris, consulted with Delambre, an astronomer of note, and procured from him written instructions as to suitable buildings and instruments for an observatory. This document was sent to the college authorities at Cambridge. No official action followed. The next of record is that the college authorities in 1815 appointed a committee to consider and report upon an eligible plan for an observatory. This is supposed to have been the first corporate action taken in the United States, having such an object in view. The doings of this committee are notable in two particulars, at least. They brought into official relations with the college for the first time, the man who was destined to be the builder and organizer of the observatory, 25 years later, William Cranch Bond.

He was about to visit Europe and was appointed the agent of the college to obtain information as to the construction and instrumental equipment of the observatory at Greenwich, and to make such plans, drawings, etc., as would enable him or another to construct an astronomical observatory at Cambridge;

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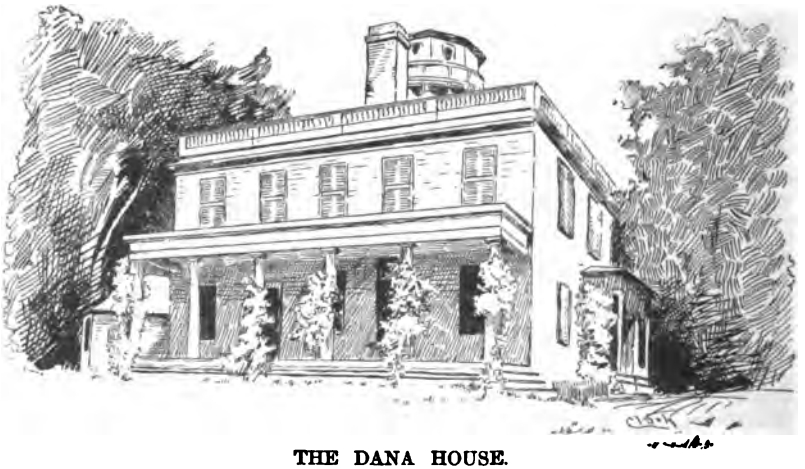
also to ascertain from the makers the cost of certain principal instruments like those at Greenwich. He performed the service and reported in detail in the following year. That nothing practical came of it for a quarter of a century was not owing to the will, but comparatively speaking, to the poverty of the college.

This result followed, however,—and it may be reckoned the second notable circumstance—that, upon his return, Mr. Bond constructed the model of an astronomical dome, the operative plan of which was the same as that of the great dome, built in 1844, and which has been in satisfactory use at Cambridge to the present time. The chief peculiarity of its mechanism is in the method of rotation by means of smoothly-turned spheres of iron. The dome rests on these at equi-distant points, and, being set in motion by suitable gearing, the iron balls sustaining its weight roll along a level circular track of iron, the circumference of which is equal to that of the dome. The method was unlike that previously in use. It appears to have been original with Mr. Bond, as is perhaps evinced by a remark in his report for 1848 referring to the matter: "If carefully examined, it will be found that this arrangement is as perfect in theory as it is appropriate and convenient in practice." Experience has shown that spheres of hard bronze are more serviceable than those of iron, and bronze is now used.

The record indicates that an observatory did not cease to be a coveted object at any time during the 25 years prior to 1840. Two antecedent events, in themselves of importance, combined to bring the long cherished project to a happy issue,—the accession of Josiah Quincy to the presidency of the college and the action of Congress in authorizing what came to be popularly known as the "Wilkes Exploring Expedition." The purpose of the expedition in part was to establish the latitudes and longitudes of uncharted places in distant parts of the world where American commerce was extending, and in part to investigate natural phenomena, including the facts of terrestrial magnetism. Having, after much delay, got an adequate appropriation, the naval department employed the best available talent of the country for the conduct of the enterprise.



THE DANA HOUSE.

Mr. Bond was engaged to make at his private observatory in Dorchester, Mass., investigations to fix a zero of longitude, whence final reference to Greenwich might be had, and to make a continuous record of magnetic observations at Dorchester for comparison with like records obtained at distant points by the expedition itself. As preliminary to the latter work, Mr. Bond tested in an isolated observatory in Dorchester the magnetic instruments with which the expedition was to be equipped.

Mr. Bond's talents were as well known at Cambridge as at Washington. What

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Mr. Quincy did in the premises can best be stated in his own words: "Early in the year 1839, the exploring expedition then being in the Southern ocean, it occurred to the president of the university that if Mr. Bond could be induced to transfer his residence and apparatus to Cambridge and pursue his observations there, under the auspices of the university, it would have an important influence in clearing the way for an establishment of an efficient observatory in connection with that seminary, by the increase of the apparatus at its command, by the interest which the observations making by Mr. Bond were calculated to excite, and, by drawing the attention of the citizens of Boston and its vicinity to the great inadequacy of the means possessed by the university for efficient astronomical observations, create a desire and a disposition to supply them."

This proposition, Mr. Quincy says in another connection, he made without having consulted with the corporation. That body sanctioned his action by making a formal contract with Mr. Bond, of date Nov. 30, 1839, the agreement on Mr. Bond's part being to make the transfer as proposed. Steps were at once taken by the college authorities to secure a subscription of $100 each from 30 different gentlemen, which sum was applied, under Mr. Bond's direction, in alterations and additions to a dwelling house owned by the college and known as the "Dana house." It still stands upon its original site at the junction of Quincy and Harvard streets, the lot being the southeast corner of what are distinctively called "the college grounds."

The cupola which crowns the roof is a reminder and proof of a part of these alterations; for within it was set up one of the telescopes of the first college observatory, the cupola when constructed being suitably domed for the purpose. Something practical in astronomy had always been taught in the college course. In this way, or possibly by Mr. Bond himself, the position of Harvard Hall on the college grounds had been determined. Thus, in a paper published by him in 1833 in the Memoirs of the American Academy, he gives the position of his observatory in Dorchester as "0°-3'-15" east of Harvard Hall in Cambridge."

That the astronomical equipment possessed by the college before Mr. Bond's coming did not amount to the beginning of a proper observatory, sufficiently appears by a contemporary letter of Prof. Joseph Lovering, written in response to an official inquiry. He says that the college had at the time "no instrument of much value for determining either time or position, and no place more convenient for using instruments than an open field, or a window which might accidentally open in the right direction." He gives the inventory, comprising an astronomical clock, which, he says, cannot be relied on for accurate time; a small transit instrument, which at one time was loaned to Dr. Bowditch, but returned, he having found it of little value; two reflecting telescopes of three feet and two feet focal length; and a refractor of three feet focal, which three, he says, "answered decently well for showing the moon, Jupiter's satellites, Saturn's ring, etc., to the students, but were very imperfect for any nice observation." These, with an astronomical quadrant and a common quadrant, complete the list. The list of instruments brought by Mr. Bond does not appear in the printed records, but in the paper above referred to he names his instruments used at Dorchester as a Gregorian reflector of 30 inches focus, equatorially mounted, an achromatic telescope of 40 inches focus, a Borda's circle, a Ramsden's sextant, and two transit clocks. The clocks he describes as "excellent," and says that they had mercurial pendulums.

In the early observations of Mr. Bond at Cambridge, priority was given to the work begun at Dorchester for the naval department. In the college record a considerable part of the routine is classed as meteorology, with reference, chiefly, to the earth's magnetism. The scheme of observation in this department was, however, much broadened, and in this the observatory appears to have performed its first notable service to pure science and to have assumed a place that gave it international recognition. For these observations the best known apparatus was procured and put into service in a building on the college grounds set at a distance from the Dana house, but connected therewith by a covered way. It was known as the "Lloyd apparatus." It consisted chiefly of three magnetometers, one for indicating declination, one for horizontal force and the third for vertical force.

It was the product of the same firm in

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England which had made like instruments for the British government for use at meteorological stations at Greenwich, Eng., Toronto, Can., St. Helena, Cape of Good Hope, Bombay, Madras, Singapore and Van Diemen's Land. The magnetic observations at Cambridge were conducted according to the same formula as that in use at these British stations, with a purpose of co-operation. In this cosmical investigation the German Meteorological Association, having many observatories under its direction, and the Russian government, having magnetic stations at various points between the borders of China and the Arctic Circle, joined. This Lloyd apparatus was the gift of the American Academy of Arts and Sciences, by vote of April 22, 1840, and was of the value of $1000.

Many interesting particulars of the early days of Harvard College observatory are given in the first volume of printed annals of the institution. In the reading an essential fact is to be kept in mind, the difference of the pecuniary standards of that and the present time. The writer of an official document of 1843, was, in view of that difference, neither inexact nor ironical when he characterized a conditional offer of $5000 for the observatory, made that year by Hon. David Sears, as "a munificent proposal." It was soon found that the Dana-house site would serve only temporarily, and on Sept. 4, 1841, action was taken for the building of a permanent observatory. Soon afterwards the present observatory grounds, then known as "Summer House hill," were bought.

Up to this time astronomical work had been carried on at the Dana house to the extent possible with the few instruments of precision at command, much of it by Mr. W. C. Bond, Jr., whose decease, in 1842, was regarded a loss to science. The contract of the senior Mr. Bond with the United States government ended in 1842, and in July of that year a movement was made having in view the purchase of a first-class telescope, but it was a matter of inquiry as to cost, etc., only. Under ordinary circumstances what was thus sought for, a proper observatory building and a telescope equal to the more difficult problems of astronomy, would have been slowly arrived at.

MAIN OBSERVATORY BUILDING, SHOWING THE DIRECTOR'S RESIDENCE AND THE GREAT DOME.

But early in March, 1843, the great comet of that year suddenly appeared in the evening sky, near to the sun. It was an astonishing phenomenon, and wrought the popular as well as the scientific mind into a state of excitement.

The comet had passed perihelion on Feb. 27, and was seen at one place in New England on the 28th, close to the sun. During its brightest period it was visible in the daytime at one place in this section of the country from 7.30 A.M. to 3 P.M., when clouds intervened; and in Mexico from 9 A.M. till sunset. It passed but about 90,000 miles from the sun's surface and through more than 300,000 miles of the sun's corona, its velocity then be-

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ing 360 miles per second. Its head was small, but its tail large and brilliant. The total light emitted by the meteor is stated by Prof. Loomis to have been equal to that of the moon at midnight in a clear sky. By the telescope its tail could be traced over a computed distance of 108,000,000 miles, so that had it been pointed towards the earth it would have passed through the planet's atmosphere and 15,000,000 miles beyond.

The professor names as its notable characteristics "its small perihelion distance, nearly as small as is physically possible, and its prodigious length of tail." It continued visible into the following month. It is known in the books as "the great comet of 1843," but for reasons which will appear, it might well be called "the Harvard comet." The friends of the young institution at Cambridge perceived that the moment was opportune for an appeal to the moneyed public. The prevalent curiosity as to the visitor could not be gratified by the observers at the Dana house.

They had no instruments fit for the occasion. An altitude-and-azimuth instrument, which had been used in the state survey of 1831, was borrowed and mounted in the cupola, and thus, on March 9, an observation was first made; but nothing came of the endeavor, it being found impossible to secure permanent adjustments. The next thing done was to call a meeting of citizens in Boston. The chairman was Hon. Abbot Lawrence. Addresses were made by Hon. John Pickering, Prof. Benjamin Peirce, Hon. William Appleton and Hon. S. A. Eliot. A financial committee was appointed, and subscriptions to the amount of $25,000 were obtained in Boston, Salem, New Bedford and Nantucket.

Thus encouraged, the official board of the college negotiated for the purchase of the best telescope that could be produced in Europe, a refractor of 15 inches aperture, equatorially mounted, the makers being Merz & Mahler of Munich. The spot for building a massive stone supporting pier on Summer-house hill was fixed Aug. 12, 1843, and ground was broken for the work on Aug. 15.

These were the experiences which Prof. Benjamin Peirce had in mind when in later years he spoke in eulogy of Prof. Bond, then deceased, in phrase which is both of historical and biographical interest. Having mentioned some of the early difficulties, he said: "When, in 1839, Mr. Bond was drawn to Cambridge by the strong hand of President Quincy, when the cause of the observatory was undertaken by the unflinching and irresistible vigor of our friend J. Ingersoll Bowditch, when even the heavens came to our assistance, and that wonderful comet of 1843 excited most opportunely a universal interest in celestial phenomena,—it was then apparent that the affection for Mr. Bond was the chief strength of the occasion, and to that we were mainly indebted for the successful attempt to obtain the unrivalled equatorial and to lay the foundations of the observatory." No proper biography of Mr. Bond, whose career was an honor to his country, has ever been published. A sketch, the facts for which have largely been derived from original sources, may fittingly be given as the next number in this series.

II.

A casual glance at the circumstances of the beginning of the famous observatory in the neighboring city of Cambridge will show that a most important contribution to the success of that enterprise was made by the first director of the observatory, Prof. W. C. Bond. The more diligently those circumstances are studied, the stronger will be the conviction that his work, while it was that of designer and organizer, was also somewhat better in the sense of being more rare in quality; that his presence and enthusiasm gave the institution vitality. The record of his life gives him title to rank among eminent Americans.

William Cranch Bond was born in Portland, Me., Sept. 9, 1789. He was the youngest son of William and Hannah (Cranch) Bond, who were natives of England. The family was of distinction there, and is genealogically traceable to the time of William the Conqueror, or earlier. The Brandon manor is said to have been granted by that monarch to the ancestor of this line, and to have been held by the family through many generations. William Bond was born in Plymouth, Eng. Richard Cranch, an uncle of Hannah, settled in Braintree, Mass., in 1751. The name, in himself and his descendants, became distinguished in the annals of the province and commonwealth. From him William Bond received information which induced him

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to emigrate to this country. He located for business purposes at Portland, then Falmouth, and engaged in cutting ship-timber at Frenchman's bay, sending the commodity to England. He made a voyage thence to England, returning with his wife and elder children. The timber business proved in the end unprofitable and he removed to Boston in 1793, where he established himself in his vocation of clockmaker and silversmith, his stand being at the corner of Milk and Marlboro, now Washington street. The youth of William C. Bond was, accordingly, spent in Boston, where he had such education as the common schools afforded. Indeed,

PROF. W. C. BOND.

that he did not have fully that privilege, may be inferred from his remark quoted by Josiah Quincy, that pecuniary restrictions "obliged me to become an apprentice to my father before I had learned the multiplication table." Mainly he was self-taught, though doubtless he derived instruction from his father, who was a well-informed man, and from some of the Cranch relatives, who were of good education. The traditions of the family and the facts of his career, indicate his mental quality to have been that of genius, one trait of which is that it absorbs congenial knowledge from unpromising materials and amidst adverse conditions.

His eldest sister wrote of him as having been, at the age of 14, "a slender boy with soft gray eyes and silky, brown hair, quick to observe, yet shrinking from notice, and sensitive to excess." She adds, in reference to his early-developed tastes: "The first that I remember, was his intense anxiety about the expected total eclipse of the sun of June 16, 1806. He had then no instrument of his own, but watched the event from a house-top on Summer street through a telescope belonging to Mr. Francis Gray, to which, somehow, he got access. In so doing he injured his eyes and for a long time was troubled in his vision." An elder brother writes of him at this early period: "He was the mildest and best-tempered boy I ever knew, and his remarkable mechanical genius showed itself very early." He adds that in devising and making bits of apparatus that boys use in their sports, William was chief among his comrades. His early apprenticeship in the clock-making business undoubtedly gave a fortunate discipline to this natural ingenuity, by confining his experiments pretty closely to the facilities of his father's workshop as to tools and materials.

He found or made "idle time" enough before he was 15 years old to construct a reliable shop-chronometer. It had to be a fixture, for lacking a suitable spring he contrived to run it by weights.

When he was about 16 years of age he made a good working quadrant out of ebony and boxwood, the only materials he had. His son, G. P. Bond, wrote of this instrument, years afterwards: "It is no rude affair, but every part, especially the graduation, the most difficult of all, shows the neatness, patience, and accuracy of a practised artist. A better witness to the progress he had already made in astronomy could not be desired. It is all that the materials would admit of, and proves that he must have been, even then, irrevocably devoted to astronomy."

How these "eccentricities of genius" were looked upon by the senior Mr. Bond does not appear, but, at any rate, William was made a member of the firm about the date of his majority, and forthwith the clockmaking business was expanded to include the rating, repairing and making of chronometers. Astronomy could now go hand in hand with "business." He must have had the means of ascertaining the true local time before he was himself owner of an in

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strument suited to that purpose. He made his first seagoing chronometer in 1812, and it was the first made in America. Its engraved trade mark was "Wm. C. Bond, 1812." It at once went into service, and satisfactorily stood the test of a voyage to and from the East Indies. For making this he had a working model; the stationary or shop chronometer of 1804 was made according to a description he found in an old French book of a chronometer used by La Perouse, the navigator. In 1810 the business of the Bonds was removed to Congress street. About the same time the family removed to Dorchester where for a while they occupied, as tenants, different houses.

Mr. Bond himself said in his later years that what first gave him a determination for astronomy was his experience of the total eclipse of 1806. Once aroused, the feeling never ceased to have sway, and it modified all his business ambitions as a chronometer maker. But as such an artisan he had excuse in the eyes of the practical minded for his loved explorations into the starry depths. In the lack of proper instruments his earliest observations were made by crude methods, which yet gave proof of his originality and of the fascination which the study had for him. It was soon after 1811 that he first gained recognition from any one competent to pass judgment upon his essential mental qualities. On Sept. 4, 1811, Prof. John Farrar of Harvard College first caught sight of a comet in the western sky. He appears to have at once notified Dr. Nathaniel Bowditch of Salem, and they two, and a few others in New England who had telescopes, traced its subsequent progress. Each of the two published an account of his observations in the Memoirs of the American Academy. Prof. Farrar having given in his introductory paragraph the date of his first observation, adds that the comet had been seen earlier by Mr. Bond of Dorchester, whom he calls "William Bond, Jr.," and says that Mr. Bond had "obligingly favored" him with the following notices:

I remarked on the 21st of April a faint, whitish light near the constellation Canis Major, projecting a tail about one degree in length, and set down its place as follows: Right ascension, 106°; declination, 9° S. April 24, right ascension, 108°; declination, 7° or 8° S. Its motion and the situation of its tail convinced me that it was a comet. I noticed it several times in May, and supposed that its motion was toward the western part of the constellation Leo.

By messages coming in sailing ships it was learned subsequently to September that the comet had been seen in Europe on March 25. Its perihelion passage was September 12, 1811.

The elder brother already quoted says of these early days: "I suppose it would cause the astronomer royal to laugh could he see the first transit instrument used by us at Dorchester, a strip of brass nailed to the east end of the house, with a hole in it to see a fixed star and note its transit; this in 1813. When we moved into the Hawes house, he procured a good granite block; we dug a deep hole and placed it at the west end of the house and got Mr. Alger to cast a stand for the transit instrument, a small one, which I think belonged to Harvard College. From this time he began to live among the stars."

The facts thus recorded of the beginning of Mr. Bond's career show his zeal and watchfulness as an amateur in astronomy, and that up to the date of the comet's appearance, and later, he had no personal acquaintance with men of science in the vicinity, since he informed none of them of what he had seen. When, months afterwards, Prof. Farrar inquired about it, the young discoverer was able to report from his memoranda no more than the degrees of position, without the minutes and seconds, and to say that he "supposed" the comet to be moving towards the constellation Leo, circumstances indicating that a strip of brass with a hole in it and a home-made boxwood quadrant were all that was astronomically in use at Dorchester as late as 1811.

That this experience with the comet was a fortunate turning point in Mr. Bond's career is evinced by Prof. Farrar's genial recognition in the paper published in the organ of American Science, where he might excusably have ignored so crude a record as that which was the best Mr. Bond could supply, and by the appearance not long afterwards, at the west end of the Hawes house in Dorchester, of a loaned telescope belonging to Harvard College.

There is no doubt that whatever previously had been lacking of opportunity to gain knowledge of the technics of astronomical science was now fully

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within his reach and that henceforth he he had the best possible of instructors and counsellors so far as he had occasion for any. Mr. George P. Bond writes of his father: "He has mentioned the names of Dr. Nathaniel Bowditch, Prof. Farrar and Tutor Clapp as those from whom he received most encouragement to continue the cultivation of astronomy. Upon his friendly intercourse with the eminent mathematician and astronomer first named he often dwelt with peculiar pleasure and warmth of feeling." The name of one other of the godfathers of the young scientist is entitled to be mentioned, that of Josiah Quincy. The lady above quoted gives an account of the setting up of the first telescope at Dorchester by her brother, and says that through it could be seen the satellites of Jupiter and the rings of Saturn. She adds that in the pursuit of astronomy up to this period "he had had no assistance whatever except from the genial kindness of Hon. Josiah Quincy, who had early recognized the future astronomer in the unpretending boy in the watchmaker's shop on Congress street, and whose kindness and encouragement never failed throughout the subsequent years."

That these men found their patronage to have been well bestowed is manifest from the action taken four years after the date of the comet by the college in making Mr Bond its delegate and agent. The board of that year consisted of President Kirkland, John Lathrop, D.D., Christopher Gore, LL.D., John Davis, LL.D., John Lowell, LL.D., and John Phillips. It is of record that the moving spirits in the matter were Prof. Farrar and Dr. Bowditch, and they were appointed a committee to prepare technical written instructions to the agent as to the general scope of his inquiry.

During his visit abroad, Mr. Bond married his cousin, Selina Cranch, of Kingsbridge, in Devonshire, the date being July 18, 1819. Soon after his return he purchased a house near to his father's residence in Dorchester, and erected on the premises a small wooden building, which he carefully equipped as an astronomical observatory. Its position is that meant in the official references to the observatory at Dorchester, and is about 45 feet southerly of the present south line of Cottage street, and 360 feet southeasterly of the centre of the New York & New England railroad bridge, over that street. Here, as one of his brief biographers remarks, "no eclipse or occultation escaped him, though occupied in business during the day in Boston," and here Mr. Quincy found him in 1839, busy in his work for the Navy Department. The period which had elapsed since the setting of the granite block and the poising upon it of the borrowed telescope had been for Mr. Bond one of constant and rapid advance in the astronomer's art. The Cottage-street observatory was built about the year 1823.

Referring to the period between 1823, or a little earlier, and 1839, Mr. G. P. Bond writes of his father: "As soon as his circumstances permitted, he imported more perfect apparatus from Europe and continued to add to his collection until it was the best in the country." And he adds this statement, which is highly suggestive as respects the enthusiasm with which the accomplished and successful chronometer maker entered upon the broader and loftier mission which destiny had in reserve for him: "When appointed by the Navy Department to the charge of astronomical and other observations, he forthwith laid out a sum of money on instruments and buildings more than ten times greater than the annual salary (to continue but four years), which he had himself proposed as an adequate compensation for all necessary expenses, and his own time, besides."

During a few years prior to 1830. he gathered materials for investigating the comparative rates of chronometers at sea and on shore. Subsequently he communicated to the American Academy the results reached, and in this paper effectually disposed of the scientific question involved, so far as it related to the interests of navigation. The authority for this statement is Mr. G. P. Bond. who also says that about the same time his father conducted a series of experiments to ascertain the influence of changes of temperature in the presence of large surfaces of iron upon the performance of chronometers; and adds that "although the conclusions arrived at were at variance with the opinions of men high in authority in such matters, they are now known to be correct."

President Quincy, in making his overture, was dealing with no novice, and, certainly, no stranger. Some intimation of what Mr. Bond had attained to is contained in the remarks of Prof. Benjamin Peirce spoken in the obituary proceed-

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THE BOND HOUSE, DORCHESTER.

View looking to the southwest. The Observatory stood contiguous to the west end.

ings of the American Academy in 1859, consequent upon Mr. Bond's decease, though the reference is to a longer period. The instrument alluded to is the great equatorial at Cambridge. Prof. Peirce said: "In his original investigations he naturally restrained himself to those forms of observation which were fully within the reach of his own resources. He did not, therefore, seek those inquiries which could only be accomplished by long, intricate, and profound mathematical computations, but preferred those which were purely dependent upon the thorough discipline of the senses. He consequently availed himself less of the remarkable capacity of his instrument for delicate and refined measurements than of its exquisite optical qualities. But when observations were required which must be passed over to the computer, his skill was not wanting to the occasion. Thus, in conjunction with Major Graham, he made that choice series of observations from which the latitude of the observatory was determined."

To this testimony as to Prof. Bond's skill as an observer may be added that of Mr. G. P. Bond as to his diligence and zeal: "There is something to my mind appalling in the contemplation of my father's labors, from the time when he was first enabled to indulge freely his passion for observation. The accumulated volumes filled with manuscript records give me a shudder at the thought of the weary frame and straining eye, the exposure, and the long, sleepless nights that they suggest."

Ex-President Quincy, upon the obituary occasion referred to, made this interesting statement as to the initiation of his project for Mr. Bond's removal to Cambridge: "This proposal, so in unison with his pursuits and talents, I expected would be received with pleasure. But it was far otherwise. In the spirit of that innate modesty which predominated in his character, and apparently cast a shadow over all his excellent qualities and attainments, Mr. Bond hesitated, doubted his qualifications for the position. He said his habits were not adapted to public station; that our combined apparatus would be small, and that something great might be expected; that he preferred independence in obscurity to responsibility in an elevated position. He raised many other objections, which need not here be repeated, as they were overcome."

At the date of this interview the president found Mr. Bond well established in a profitable manufacturing business, happily situated in his domestic and neighborhood surroundings, with an avocation fascinating enough to occupy all his leisure and a fame extensive enough to satisfy his own modest estimate of his abilities. There was no pecuniary betterment for Mr. Bond in the suggested change. Mr. Quincy could only offer him

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what he had already, a family domicile; so that the proposal might warrant an adaptation of Sidney Smith's famous phrase and be described as an invitation to come to Cambridge and "cultivate astronomy upon a little oatmeal." In so phrasing it there is no disparagement of the college; it was the day of small things, of pennies, not dollars, in the college treasury. But the event speaks the praises of Mr. Quincy, whose sagacity was unfailing and before whose persuasiveness and energy difficulties in administration were wont to give way, and of Mr. Bond, whose unselfishness and loyalty to science were proof against pecuniary considerations. In mental traits each was in many respects the complement of the other, and it is not too much to say that these two were pre-eminently the founders and builders of the observatory.

The official report for 1846 states that up to that time the labors of Mr. Bond had been "entirely unrequited, except by the gratification of his love of science and of home," and suggests that this devotion to the institution at Cambridge was the more marked in that during the preceding spring he had declined "the almost unlimited offers made to him by the administration at Washington to induce him to take charge of the observatory there." It is known, also, that frequent expenditures of his own money were made during this period for current expenses and for things convenient in conducting the observatory, sums small severally, no doubt, but considerable in the total. In 1846 a sum equal to the proposed salaries for the next two years was subscribed by citizens of Boston, and in 1849 the official board was able to report that "through a bequest of $100,000 made by Edward Bromfield Phillips they should thereafter be relieved from anxiety as to the payment of salaries and current expenses." Various official documents evince that during the first eight years Mr. Bond is to be regarded not in the character of an employee, but a benefactor of the college; that his labors were deemed by those most familiar with them to be indispensable and invaluable, and that his friendship for the college, manifested in all ways, and especially in his declination of the liberal offers coming from Washington, was appreciated and honored. The date of Mr. Bond's appointment as director of the observatory was Feb. 12, 1840, though the confirmation by the corporation was later. He was given the honorary degree of A.M., by Harvard in 1842.

III.

In resuming consecutively the story of the half-century's progress of Harvard College Observatory, which was interrupted in the preceding number to give place to a biographical notice of Prof. W. C. Bond, it may be remarked that the period of his official term, which covered 19 years, was fruitful in great discoveries and events in the astronomical department of science. Harvard Observatory contributed its full share, though the greatest of all was that which gave fame to Le Verrier, the French astronomer, the discovery of the planet Neptune. In September, 1844, the observatory building on Summer House hill had been completed to the extent proposed at that time, and the instruments were transferred from the Dana house.

A new transit instrument, imported by the United States government for the use of the Northeastern Boundary Commission, was set up in December, and used during the winter in observations for ascertaining the latitude, as previously described in the quotation from Prof. Peirce. The results were collated and discussed by Prof. Peirce in the memoirs of the American Academy. These were the first notable observations of precision at the new observatory. The longitude was also determined by the most accurate method then known, observation of occultations and moon culminations and comparison of a considerable number of chronometers transported to and from Greenwich by ocean steamers. In the ultimate determination the record made by several hundred chronometers thus sent to and fro, and observations of occultations, etc., in Dorchester, Cambridge, Brooklyn, Philadelphia and Washington, ranging through many years, were brought into the account. The earliest were observations made in Philadelphia in 1769. After the laying of the Atlantic cable still closer comparisons with the zero of Greenwich were possible. The position of the observatory as finally determined and now offi-

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cially of record is: Longitude, 71° 7′ 44.85″ west; latitude, 42° 22′ 47.6″, north. As showing the error of the best attainable results by use of chronometers it may be remarked that by that method the central tower of the observatory was located at a point on the lawn half way between the front door of the director's dwelling-house and Garden street. The discrepancy is about 320 feet.

About the time of the first determination Commodore Owen of the British Navy was making an official survey of the coast of New Brunswick and Nova Scotia. Having confidence in what had been done at Cambridge he took that station for his zero in preparing his official report, ultimate reference being made to Greenwich. The first importation of chronometers appears to have been made jointly by Prof. Bond and Commodore Owen. When the report was submitted it was challenged by some of the British Board of Admiralty, who believed that the longitude of Halifax was better known. In due course Prof. Bond was inquired of, and his letter addressed to the board of admiralty, in explanation of the technicalities, proved convincing and its conclusions were cordially accepted, with thanks by Admiral Beaufort on behalf of the board. The officers-in-chief of the United States Coast Survey, and of the exploring expedition severally adopted the Cambridge meridian as the zero in preparing their official reports.

A new instrument purchased by the observatory, a 2¾-inch equatorial, permitted accurate observations to be made of the solar eclipses of 1845 and 1846, the comets of the same years, the transit of Mercury in 1845 and of the newly discovered planet Neptune.

The 15-inch equatorial was set up on June 23 and 24, 1847. Certain nebulæ and the planet Saturn were the first subjects of study. Discoveries of importance were made in each field of investigation. The report of the visiting committee for 1848 notes the discovery by Prof. Bond on Sept. 19 of that year of the eighth satellite of Saturn, and speaks of it as "the only addition to the solar system ever made on the continent of America."

The few years immediately following the date of the great telescope may be called the romantic period in the history of the observatory. There was no instrument on this continent to be compared to it, and it had but one equal in Europe.

While the director of the observatory kept cool enough to utilize it to the utmost, he manifestly shared in the enthusiasm. One of the earliest to inquire what could be seen by it was Edward Everett, president of the college from 1846. Prof. Bond responded by letter on July 26, 1847, named several matters and ended by saying: "But I must recollect that you require of me only a brief account of our telescope. The objects revealed to us by this excellent instrument are so numerous and interesting that it is difficult to know where to stop." On Sept. 22 following Prof. Bond wrote to the president: "You will rejoice with me that the great nebula in Orion has yielded to the powers of our incomparable telescope."

He explains the reason for his rejoicing by saying that this nebula and that of Andromeda had hitherto been the strongholds of the "nebular theory," or the theory that the nebulæ are masses of matter in process of condensation into systems.

Now, the mass in Orion which, he said, had defied the telescopes of both the Herschels, and, at first, that of Lord Rosse, had been resolved into innumerable distinct points of light, or separate stars, by the Cambridge refractor, whose only competitor in the search was Lord Rosse's instrument, "the largest reflector in the world."

The phrase "incomparable telescope" was warranted. Nor does the didactic suggestion of the proverb about the new broom apply; for more than 30 years afterwards the present director of the observatory had occasion to say: "In 1877 besides the photometric measures of the satellites of Mars, a series of measures for their positions was also made. The number of these observations was second only to that obtained with the great telescope at Washington." Of the work done two years later, he says: "Of the satellites of Mars 1348 measurements were made, Deimos being last seen at this observatory as it gradually receded from the earth. This is remarkable, as our telescope has entered into competition with the largest telescopes of the world, some of which admitted two or three times as much light."

On Nov. 7, 1848, a transit circle was set up and it completed the set of new instruments at first proposed for the ob-

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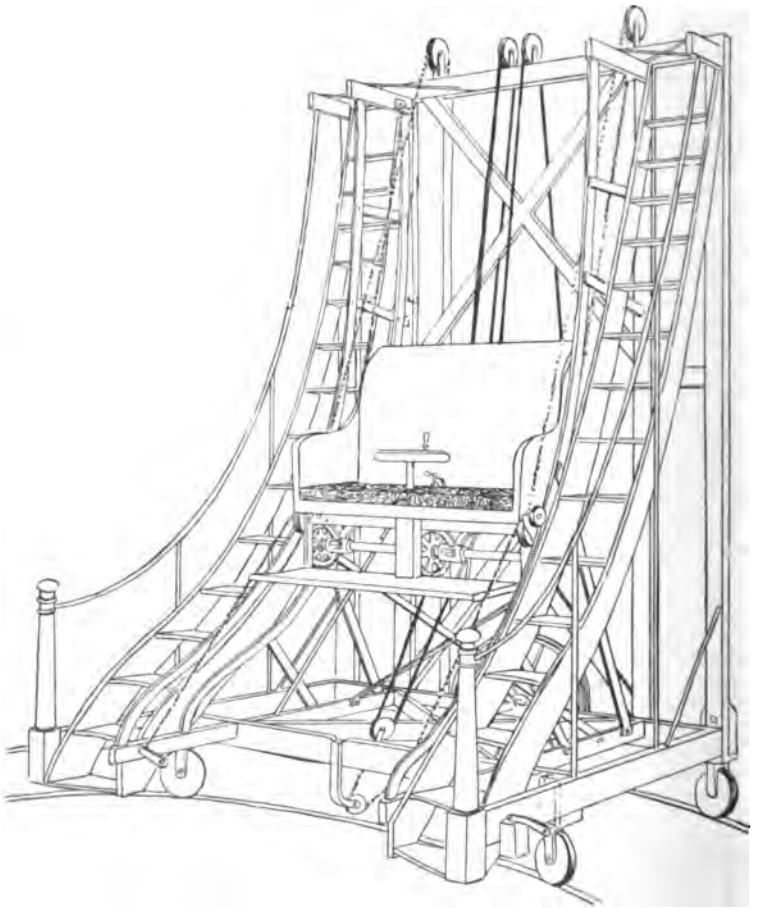
servatory. Previous to this date two new "comet seekers" had been received, the gifts respectively of President Quincy and Mr. J. I. Bowditch. With these in the six years beginning with 1845 the original discovery of ten comets was made by Mr. G. P. Bond. In his report for 1846 Prof. Bond says that during that year stellar and lunar observations had been made in co-operation with like work done by observers of the United States Coast Survey at West Point, Philadelphia and Nantucket, to determine longitudes for the purposes of the coast survey.

But visions of the sky were not the only matters of interest at the observatory in this early period. The great telescope was poised at a height of 13 feet from the floor of the dome, and its sweep was from three degrees beyond the zenith to as many below the horizon. The visual end of the instrument therefore might need to be set at any point along an arc of 90 degrees, and an observer would have to be something of an acrobat in successfully using it unless a suitable chair could be obtained. There was none in the world that filled all the requirements, and Prof. Bond invented and made one. It is in use, unchanged, to this day, and by means of its ingeniously combined wheels, cogs and pulleys the



W. C. BOND'S OBSERVATORY CHAIR.

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observer can quickly and easily place himself anywhere along the vertical quarter circle and horizontal full circle traversed by the eye-piece of the telescope.

Prior to 1845 a transfer of 12 chronometers to and from Greenwich, Eng., had been made by Prof. Bond and Commodore Owen, for the determination of the longitude of the observatory. Other chronometer expeditions were conducted subsequently in co-operation with the United States Coast Survey, the final one being in 1855. In the summing up of results, 723 independent chronometer records were used. The magnitude of this undertaking, as a whole, surpassed anything ever attempted in any other country.

In his report, reviewing the year 1848, the director says; "Some experiments made with the daguerreotype and talbotype processes for obtaining impressions of the sun's image formed by the telescope have not been attended with complete success; however, we do not despair of ultimate success."

In the report for 1850 he is able to say: "With the assistance of Mr. J. A. Whipple, daguerreotypist, we have obtained several impressions of the star Vega. We have reason to believe this to be the first successful experiment ever made either in this country or abroad. From the facility with which these were executed with the aid of the great equatorial, we were encouraged to hope for further progress." In the report of the following year he speaks of pictures of the moon and stars obtained by this process, and adds with reference to his son's official visit to Europe that year: "Some of these daguerreotypes taken by the aid of our great object glass excited the admiration of eminent men in Europe, to whom Mr. G. P. Bond gave specimens." In an official letter he says of his son's visit to Paris: "He attended in May a meeting of the French Academy, and there presented a daguerreotype of the moon taken with our large telescope." Other specimens were placed in the great exhibition of London, or World's fair, of that year, and a council medal was awarded for them.

This tour in Europe by the younger Mr. Bond makes an interesting episode in the general record. He was everywhere cordially received by men of science, a fact attributable in part, no doubt, to his own reputation, but more especially to his being the representative of the new observatory, already of fame, established in the distant West.

On arriving at Cronstadt he was surprised at meeting an officer of the Russian government who had instructions to conduct him to the imperial observatory at Pulkova, where, during his stay in Russia, he was made the guest of the director of the observatory and given all possible attentions and facilities, including the "great privilege" of practically manipulating the instruments. Among these was the great telescope, the rival of the Harvard equatorial. During the tour he visited Sweden and saw a total eclipse of the sun. Among those from whom he had friendly receptions were Baron Humboldt, Sir John Herschel, Sir David Brewster, Sir G. B. Airy, Le Verrier, Biot Argelander, Gauss and Hansen; also Lord Rosse, whose great telescope he had opportunity to use.

In July, 1848, the wires of the magnetic telegraph were connected with the observatory at the expense of the coast survey, for determining by instant communication the longitude of certain principal cities in the United States. There are suggestions of both the modern and the antique world in the statement that in this first experience the electrical apparatus of a department of the institution founded by John Harvard, was connected with like apparatus in an observatory in the garden of Peter Stuyvesant in New York city. These electrical experiments of the coast survey were begun as early as 1844, between Washington and Baltimore.

Various improvements of method had been made, and that most approved was followed on this first occasion at Cambridge. The coast survey officer in charge had for his assistants Prof. Bond at Cambridge and Prof. Loomis in New York. An official letter of the electrician of the Coast Survey Department says: "During these experiments Prof. Bond conceived the idea of using an automatic circuit-interrupter."

Some question of priority as to this suggestion arose in later years. It was doubtless a spontaneous and original thought with Prof. Bond, though the suggestion appears to have been made earlier elsewhere, but it had not been acted upon "from apprehension of injury to the performance of an astronomical clock which must be used for the purpose." Experience

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proved eventually the apprehension to have been groundless; but Prof. Bond's suggestion avoided any liability of the kind by proposing that an astronomical clock be made for the purpose.

In August, 1848, he received authority to have such a clock made at the expense of the coast survey. Reverting to the matter in a subsequent annual report, Prof. Bond says: "I caused such a clock to be made, and it is found to answer perfectly the intended purpose. But another and far more serious difficulty presented itself in the accurate registry of the beats of the clock after being transmitted by the galvanic circuit; and it was at this point that further progress

DAVID SEARS,
The First Donor to the Observatory.

in the application of this method to astronomical observing was arrested."

Experimenters were busy at Philadelphia, Cincinnati, and elsewhere, during the two years' interval in attempts to solve this concomitant problem, and with very considerable success. That none of these devices quite filled the requirements is manifest by the fact that they did not go into general use. But the perfected apparatus submitted to the officer of the coast survey by Prof. Bond, April 12, 1850, did go into such use. This instrument Prof. Bond stated to be the joint invention of himself and his two sons, George P. and Richard F. Bond. It was named at first from one of its peculiar parts, the "spring-governor," but the more comprehensive title of "chronograph" was later applied to it.

While as a piece of mechanism, it was distinct from the "circuit interrupter," the two were used conjointly, and thus acting in combination their operation in recording became known soon afterwards in England as "the American method." By this method the errors suggested by the term "personal equation" are greatly diminished, and a definiteness of record is attained, which permits the recording sheet to be read by the eye to tenths and by scale and lens to hundredths of a second. The successive sheets are the primary official record, and being bound into volumes, become a part of the permanent archives.

The apparatus was at once put to use in the several telegraphic stations of the coast survey; and one of the circumstances which made Mr. G. P. Bond's tour in Europe a notable one was its exhibition for the first time there. It was shown in operation and explained in a lecture by him before the Royal Astronomical Society, and also at the annual meeting of the British Association for the Advancement of Science. Through the urgency of Sir David Brewster and others it was set up in the great exhibition at London in 1851, where a medal was awarded for it. It had the highest award of the Massachusetts Mechanic Association, a gold medal. It was adopted at the Greenwich observatory soon after Mr. Bond's exhibition of his model, and speedily throughout Europe.

Soon after the electrical experiments of 1848 at the observatory the wire was put into use to transmit to Boston and different railway points, signals giving the true local time, these signals being electrically responsive to the movement of an astronomical clock in the observatory, the method of transmission being that of the "circuit interrupter." This system was at once adopted in England, wire connections being made with a clock in Greenwich Observatory. This time service of the Harvard Observatory, though continued during the intermediate period, was not organized as at present until 1872.

In 1852 the officers of Harvard Observatory co-operated with Captain Charles Wilkes in experiments for ascertaining the velocity of sound under different atmospheric conditions. In these tests cannon were fired near the observatory, at the arsenal in Watertown, at the navy

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yard in Charlestown and at Fort Independence in the harbor, the central observing point being the cupola of the State House in Boston, where Captain Wilkes took his station. These experiments had immediate reference to a reduction into proper form of data obtained by the exploring expedition, wherein Captain Wilkes had caused surveys of islands and groups in remote seas to be made by sound. In these surveys, distances between points whence angles were projected were determined by the firing of cannon at those points.

In 1855 an endowment of $10,000 was made by ex-President Quincy as a memorial of his father, Josiah Quincy, a patriot of the revolution. This fund was specifically applied to the publication of annals of the observatory. The first volume was issued in 1856 and comprised a review of the work of the preceding years, so that the series of which it is the initial number makes a continuous record from the beginning. The series now numbers nearly 25 volumes. The decease of Prof. W. C. Bond occurred Jan. 29, 1859.

IV.

George Phillips Bond was the second director of Harvard College observatory, being the successor of his father, Prof. W. C. Bond. The date of his appointment was 1859. He was born in Dorchester, Mass., May 20, 1825, and graduated at Harvard in 1845. Thenceforth until his decease Feb. 17, 1865, he was in the constant service of the observatory. Prior to his taking the chief office his labors as assistant had gained for him a professional reputation; he had shared with his father the heavy task of organizing the observatory and carrying it on with slender means; he was familiar with its routine, and both by academical and practical training was peculiarly qualified for the position.

His professional record therefore is not to be limited to his own term as director. The computations required in the preparation of the three early volumes of the annals were to a great extent his work, and those pertaining to the chronometric expeditions between Boston and Liverpool, were wholly by him. He was the discoverer of the dark interior ring of Saturn, one of the first revelations of the great telescope, and discoverer also, as already stated, of ten comets within a brief period of years. In this cometary work it was his practice to sweep the whole visible heavens once every month.

His observations of Saturn led to the adoption of a new theory as to the constitution of the rings. During his term systematic observations were made of certain nebulæ, particularly that in Orion. He conducted a series of zone observations of faint stars near the equator, prepared a plan of observation and reduction, and with his own hand graduated the mica scales used in the work.

In 1860 he made an investigation of the brightness of certain celestial objects, including the moon and the planets, the results of which have a special value but are not identified with the Harvard photometrical series of later years, which relates to fixed stars only. During his term the formation of a star catalogue was begun, the observations being made with the meridian circle and in right ascension only, and much progress was made in picturing celestial objects by the camera, the process having, with the disuse of Daguerre's particular method, gained the generic name of photography.

The prestige of the beginning and early successes of astronomical photography attaches to the administration of the senior Bond; but his son shared fully in the labors of thought, contrivance and manipulation by which the original experiments were conducted, and in appreciation of the future possibilities to science in this new method of observation.

One evidence of this appears in a paper read by the younger Mr. Bond before the American Academy on May 12, 1857, the immediate occasion for its presentation being a most significant discovery made at the observatory a few days earlier.

The paper says: "Daguerreotype images of the star Vega were obtained at the observatory of Harvard College on July 17, 1850, and subsequently impressions were taken from the double star Castor, exhibiting an elongated disc, but no separation of its two components."

"These were the first, and until very recently, the only known instances of the application of photography to the delineation of fixed stars. A serious difficulty was interposed to further progress by the want of suitable apparatus for

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communicating uniform sidereal motion to the telescope.

"This has been supplied by replacing the original clock of the great equatorial of the observatory by a new one, operating on the principle of the spring governor. Immediately upon its completion, a new series of experiments was commenced. These have been successful in transferring to the plate by the collodian process, images of fixed stars to the fifth magnitude, inclusive, with singular and unexpected precision. The most remarkable instances of success are the simultaneous impressions of the group of stars composed of Mizar of the second magnitude, its companion of the fourth and Alcor of the fifth magnitude. The following measurements of the angular distance of the companion from Mizar were taken from the plates."

A tabulated statement follows in the paper, giving dates from April 27 to May 8, with measurements from 13 photographic negatives produced on the respective dates. The mean for distance is 14.49 seconds, and for angle of position, 147°.80. For the same stars observed in the usual way, Struve's mean of six observations is, for distance, 14.40 seconds; for positions, 147°.40.

Mr. Bond's comments are: "The photographic method has thus in its first efforts attained the limit of accuracy, beyond which it is not expected the other can ever be sensibly advanced.

"Should photographic impressions be obtained from stars between the sixth and eleventh magnitudes as has already been done for those between the first and fifth, the extension given to our present means of observation would be an advance in the science of stellar astronomy of which it would scarcely be possible to exaggerate the importance."

Mr. Bond made important contributions to the literature of the science both in its mathematical and practical departments. Among the more notable

THE GOLD MEDAL; REVERSE SHOWING SIR WILLIAM HERSCHEL'S 40-FOOT TELESCOPE.

of the former was a paper on cometary calculations and the method of mechanical quadratures, valuable in various respects, and notable in having anticipated an important improvement afterward given independently by Encke; also a paper on the use of equivalent factors in the method of least squares. He wrote a monograph covering observations of Donati's comet of 1858, for which he was awarded the gold medal of the Royal Astronomical Society and was the first of his countrymen to obtain that distinction. He began a paper on the nebula in Orion, which he did not live to complete, though during his prolonged last illness he continued his labors upon it, and dictated to an amanuensis long after strength to write had gone from him.

This paper was afterwards finished by Prof. T. H. Safford, then of Harvard, now of Williams College observatory. A biographer says of Mr. Bond: "Science to him was not a pastime but a serious calling, to be pursued with the utmost conscientiousness and singleness of pur-

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pose. That he did so much and did it so well, during the few years allotted to him, must have been partly owing to an

PRESIDENT JOSIAH QUINCY.

extreme reluctance to dissipate his powers by beginning new works while the old were still unfinished." He received the honorary degree of A. M. from Harvard in 1853.

V.

Joseph Winlock was the third director of Harvard College observatory, being appointed in 1866. He was born in Shelby county, Ky., Feb. 6, 1826; he graduated at Shelby College in 1845, and was professor of mathematics and astronomy there until 1852. He was subsequently in the service of the Naval Observatory at Washington, and, still later, instructor in mathematics at the Naval Academy at Annapolis. At different dates, he was superintendent of the work of preparation of the Nautical Almanac. He continued in office as director of the observatory until his decease, June 11, 1875.

His administration appears by the record to have been one of various activity. A large amount of improved apparatus was added to the resources of the observatory, partly by purchase and partly by invention and making on the spot. He kept up the reputation of the observatory, which has never failed from the start, for originality and ingenuity in mechanical devices. It was during his term that the transmission by electricity of the true solar time to railroad centres and business points in all parts of New England became a regular part of the observatory work, and, by the system which he organized, compensation was made by corporations and individuals whose clocks were put into electrical connection with that at the observatory.

A considerable revenue has thus annually been derived. Other electrical apparatus of the observatory was modified and improved. A "switch-board," the device of his predecessor was much elaborated in its mechanism, whereby the electrical current was made more available and all the principal instruments were connected at will with the chronographs.

In 1868 when he visited Europe he procured the apparatus of a meridian circle of the latest device, the lenses being made in Cambridge. In setting up the instrument he saw opportunity to introduce various improvements in mechanism.

These were approved by experience and went into general use elsewhere. Another of his devices was "for the determination of absolute personal equation by mechanical means." Other contrivances, either wholly original or ingenious modifications of known apparatus, were an attachment to the spectroscope for automatic recording, being a modification of the chronograph; a combination of a stationary plane mirror with a fixed lens of great focal length — from 30 to 40 feet — for photographing the sun; a later improvement of this, by which the telescope was reduced to a single fixed lens of long focus and small aperture, chromatic aberration was avoided and the image on the plate could be made as large as was convenient for measuring; and a change of method by which the sun's image could be taken at the principal focus of the object glass and not beyond an eye-piece used to enlarge the image.

In February, 1866, when he took charge of the observatory, the great equatorial was applied to a series of observations of

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double, and especially binary stars. This investigation was continued as steadily as circumstances would permit till 1872, and the results appear in the annals. In 1867 the first spectroscope owned by the observatory was imported, and in 1869 another. Two small direct-vision spectroscopes were also procured during Prof. Winlock's term.

In 1870 the new meridian circle, a superior instrument, was set up, and on Nov. 10 of that year was begun the series of observations for position of stars in the "Cambridge zone," so called, or that between 50° north and 55° north and overlapping 10′ upon each contiguous zone. The standard in using this instrument was an artificial star produced by lamplight.

During this term two expeditions were made with apparatus for observing total eclipses of the sun, and in both satisfactory results were obtained. On the first occasion, of date Aug. 7, 1869, the station was at Shelbyville, Ky., and on the second, of date Dec. 22, 1870, at Jerez de la Frontera, in Spain. In 1867 daily observations in terrestrial magnetism were made at the observatory for the purposes of the coast survey. In March, 1869, experiments for determination of longitudes were conducted on a continental

HARVARD OBSERVATORY STATION IN SPAIN.

This survey was a joint enterprise conducted by certain of the great observatories of the world, that of Harvard being one of the two in this country having a share in the work. On July 4, 1870, was begun a series of photographs of the sun, and the work was continued nearly or quite to the end of Prof. Winlock's term, many hundred photographs being comprised in the list.

In September, 1871, was begun an elaborate investigation of lunar phenomena, which continued a year. In 1871 an arrangement was made with the coast survey by which a series of photometric observations was carried through, and for this a Zöllner astro-photometer was imported. The work was continued three years, though not all of it at Cambridge. The results are in the annals in 1878.

scale, wire connection by relays being made with San Francisco. In these experiments apparatus which had been modified by Prof. Winlock was used and by this method, and also by another which was applied, it proved that the time of passage of a signal from Cambridge to San Francisco through the wire and six relays was very nearly three-quarters of a second. Between Dec. 13, 1869, and the summer of 1872, electric signals were sent by the Atlantic cable to and from Brest in France, via Duxbury, Mass.

The purpose of these tests was to establish with precision the difference of longitude between America and Europe. Prof. Winlock supervised the work of preparing and engraving a series of plates illustrating remarkable celestial

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objects. These gave special value to the volume of annals in which they appeared, causing an unprecedented demand for copies, so that it is now a rare book. His publications were not numerous, but there is no doubt that his scholarship, versatility and wide experience would have yielded valuable additions to the literature of science had his life been prolonged.

The means at command during his term did not warrant the publication of many volumes of annals. Though for nearly 10 years in office he did not live to

PROF. JOSEPH WINLOCK.

see any of his own observations published or even to complete the work of his predecessors.

During the term the permanent funds of the observatory were increased by the bequest of James Hayward $20,000, and that of James Savage $20,000. In 1870 a subscription of $12,450 was completed for purchase of a new meridian circle. In the preceding term a gift of $10,000 was made by William Sturgis for the publication fund. Prof. Winlock had the honorary degree of A.M. from Harvard in 1868.

VI.

Edward Charles Pickering, the present director of the observatory, was appointed in 1876. He was born in Boston and is of the Essex family of the name, Colonel Timothy Pickering being his great-grandfather. He is a graduate of the Lawrence Scientific School of the class of 1865. During the next two years he was a teacher of mathematics in that department of Harvard University. Later and up to the time of his appointment as director, he was professor of physics at the Massachusetts Institute of Technology.

A system of teaching physics called the "laboratory method" was introduced by him there, and his text-book illustrative of the method has to a great extent been adopted by like institutes. Astronomy, as a department of physics, came into the general course, and the attention necessarily given, for the purposes of instruction in the institute, to the technics of that subject, and to demonstration, served as preparation and discipline for the official responsibilities which he afterwards assumed.

He was a member of the Nautical Almanac party for observing in Iowa the total solar eclipse of 1869, and was in like service in the following year as a member of the United States Coast Survey party which observed in Spain a recurrence of that event.

When he came to the directorship he found the observatory to be well equipped as to instruments and its small working force efficiently employed. Their number was but five or six, which was all the means of the institution permitted of.

Like pecuniary restrictions continued until 1879, when a subscription was completed providing for the institution, $5000 annually for five years. Since then much larger gifts have been bestowed and the instrumental equipment, in recent years especially, has been whatever the latest demands or suggestions of science called for; the observatory staff has been augmented from time to time, till it now numbers about 40 persons, and the field of observation has been extended to include the southern hemisphere of stars.

Upon the premises at Cambridge where in 1876 stood only the main observatory and a lesser adjunct structure are now eight or ten others, a cluster of small wooden buildings, domed or otherwise adapted for astronomical uses, each containing a costly instrument of the most approved device; and besides these a dwelling house has been transformed into a hall, or rather a workshop of photography, and makes the northernmost structure of the little city of science

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which has been set upon Summer House hill.

Upon Mt. Wilson, in California, in north latitude, and Mt. Harvard, in Peru, in south latitude, stand other unpretentious buildings, from within which observers of the Harvard corps nightly search through the translucent upper atmosphere of those regions to the respective poles. This aggregation of means has yielded ample returns; to say which is to signify that during the period under consideration the institution has made a noteworthy record, and that its affairs have been guided with befitting skill and judgment.

The total permanent funds at the beginning of the present term amounted to about $170,000. The subscription for five years was intended for immediate expenditure. At the end of that period a permanent fund of $50,000 was obtained in like manner. In 1885 was added to the permanent funds the bequest of Robert Treat Paine of his whole estate, of which $164,198 became at once available. In 1886 was made the first of a series of annual gifts of large sums of money by Mrs. Anna P. Draper of New York as a memorial of her husband, the late Prof. Henry Draper. These gifts have constantly been applied in furtherance of photographical observation, especially in that line of investigation which Dr. Draper himself began in his lifetime. In 1887 the bequest of Uriah A. Boyden, amounting to $238,000, became available. This bequest has conditions providing for astronomical work at considerable elevations as free as possible from disturbing or obstructing conditions of atmosphere. The income of the Paine fund may be applied generally.

In pursuing the inquiries thus suggested, and others, the observatory has adhered to its traditions, wherein original investigation has been directed to the physical rather than the mathematical side of astronomical science.

In his first annual report the present director outlined the immediate policy, in the then restricted state of the finances, to be to keep employed chiefly the two most costly and effective instruments, the great equatorial and the meridian circle. The latter was already in constant use in the work of the Cambridge zone.

With reference to the former, the report having named the several specialties which the great observatories of this country had taken, each to itself, said: "Photometry offers a field almost wholly unexplored with large telescopes either in this country or abroad. It has therefore been selected as that to which the greater portion of the time of our telescope will be devoted."

The investigation thus entered upon, together with the zone observations just mentioned, and the continuation by ampler and in some particulars radically different methods of investigations in spectroscopy and photography, have given the institution a wide renown. But hardly less conspicuous are certain other achievements in the long list which makes the complete record. Without attempting to give any of these rank, still less to repeat the list, a few may here be mentioned upon the ground of their presumed popular interest.

In 1878 the utility of the time signal service was increased by causing a time ball to be dropped every day at exact noon from a conspicuous point in Boston within view of the shipping of the harbor. The time was that of the meridian of the State House in Boston. When the standard or 75th meridian time went into general use the practice was conformed thereto. Indeed, the terms of the proposition might be reversed so as to indicate that, in the final determination, the responsibility was put upon the observatory to lead off in the matter.

There had been some discussion in the public prints and elsewhere of the advisability of adopting a common meridian time for large areas. In the report of the observatory for 1878 the theoretical presentation of the case which had been made by those advocating the change was sanctioned, and the new time was recommended as sure to be of public convenience if generally accepted. General consent was somewhat slow in its manifestation, but eventually the managers of all the principal railroads of New England agreed to adopt the plan if the time-signalling system of the observatory should be made to correspond in respect to clock connections, time ball, etc.

This was instantly agreed to, and with due prior public notice the new time went into use Nov. 18, 1883, and the Boston noon ball was first dropped on that day at exactly five hours later than the noon of Greenwich.

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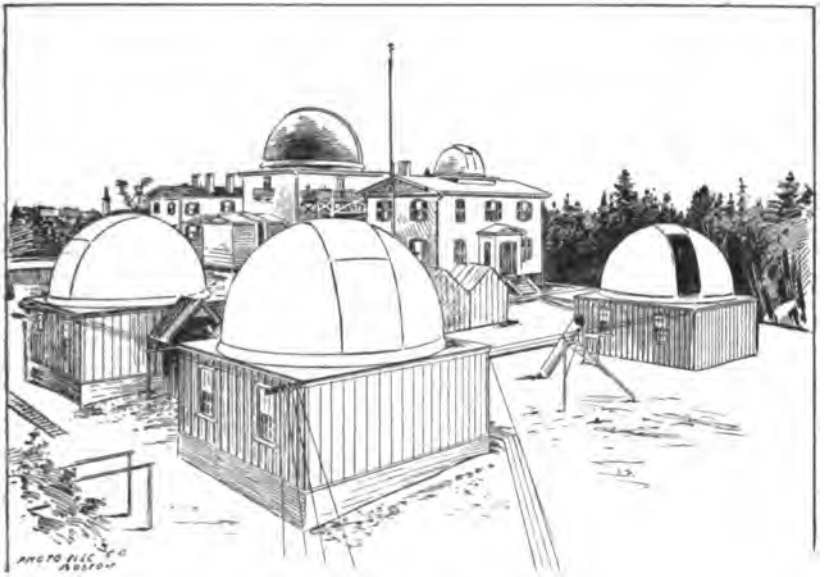
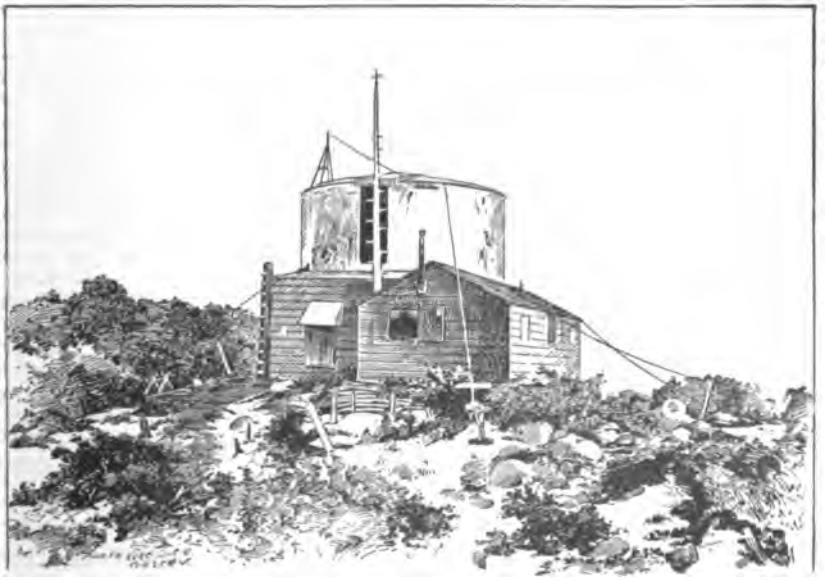


HARVARD COLLEGE OBSERVATORY.



HARVARD STATION IN CALIFORNIA.

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In 1880 the full routine of meteorological observation was abandoned, as several institutions were doing like work. The record of the observatory in meteorology, which had continuously been kept up for 40 years, was reduced to proper form for printing, and was published in 1889. Certain observations of this kind have, however, been continued in the record to the present date.

In 1888 a plan of co-operation was agreed upon with the N. E. Meteorological Society and Mr. A. L. Rotch of the Blue Hill, Mass., Observatory, by which their results, which are of a comprehensive character, have since been published in the annals of the Harvard Observatory.

In 1877, in co-operation with Miss Mitchell of Vassar College Observatory and her assistants, observations were made at Cambridge for determining the longitude of the Vassar Observatory. Between Feb. 15, 1879, and Jan. 3, 1880, like observations were made in co-operation with officers of the Winchester Observatory of Yale College to ascertain the longitude of that institution. Between June 2 and June 23, 1883, similar work was done to fix the longitude of McGill Observatory in Montreal.

In the summer of 1888 ten evenings were given for observations for the longitude of Smith College in Northampton. The observers were Miss Byrd, teacher of astronomy at that college, and Miss Whitney, professor of astronomy at Vassar College. Harvard's contribution in the affair consisted in providing facilities on the spot, including the use of a transit instrument. These are instances, which among others go to show that because of infinite painstaking at Harvard in the earlier years it has become the Mecca to which all on this continent who wish to be perfectly assured in the matter of longitude may prudently make a pilgrimage.

In 1881 an arrangement was entered into for prompt communication as to unusual celestial phenomena, discoveries, etc., among astronomers in this country and in Europe. A cipher code, the invention of Messrs. S. C. Chandler and John Ritchie, Jr., of the observatory staff, was put into use. It is known as the "Science Observer Code," and as it is superior in accuracy to former codes has been widely recognized. In 1883 Harvard observatory was made the official distributing centre for this class of news, by consent of the Smithsonian Institute, which had previously performed the service.

Upon the occasion of the transit of Mercury across the sun's disk in May, 1878, all the available telescopes of the observatory were put to use. The results, which included many photographs, were satisfactory, considering the unfavorable weather. During the like transit of Venus, on Dec. 6, 1882, six telescopes being in use, large additions were made to the important data which planetary events of this kind may supply.

In August, 1886, a small party provided with instruments belonging to the observatory made an expedition to Grennada, near the northern coast of South America, for observation of the total solar eclipse of that year. The expedition was in charge of Mr. W. H. Pickering, who afterwards became a member of the observatory corps.

On Jan. 1. 1889, a large party, under the same direction, observed a recurrence of the event in California. The observations were mainly photographical. Excellent results were obtained in both cases, though less in amount in the former, because of unfavorable weather.

Much has been done during the term in cometary investigation, but latterly comets have been observed, as a rule, only immediately upon discovery and towards the end of their visible period, or after they had got beyond the reach of any but the most powerful telescopes.

In the summer of 1883 the director journeyed in Europe and visited the principal observatories there. In the following annual report he names as an important result of his journey the obtaining of copies of unpublished manuscripts of Argelander and Sir William Herschel. The former are memoranda of observations of variable stars and the latter of observations made more than 100 years ago of the light of all stars of Flamsteed's catalogue.

The work on the Cambridge zone of stars was completed, as respects the primary plan of observation, on Jan. 26, 1879, and at that stage was regarded as one of the largest astronomical undertakings ever carried through in this country.

The reduction of the data was accomplished in 1883, but as was expected, a

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necessity for reobservation appeared in certain cases. This work was done between Oct. 9, 1883 and Aug. 9, 1884. The observer from the beginning had been Prof. William A. Rogers. He resigned his position as assistant professor in the observatory in 1886, but continued to serve as editor of the published results. The whole series makes half a dozen or more volumes of the annals. The European supervisors of the general undertaking, well pleased, apparently, with the early instalments of manuscript returns, assigned to Harvard the work of reobservation of another zone, that between 9° 50′ south and 14° 10′ south. This work is still in progress. Each zone comprises about 8000 stars or nearly 17,000 in all.

The publications of the observatory during the present term in the form of annals, and as contributions by members of the corps to various journals of science, have been numerous and extensive. At the beginning of the term but four volumes of annals had been issued, though about an equal number were in some stage of progress in the printers' hands, publication having gone on slowly from lack of means. At the present time the continuous series of 22 volumes has been issued, excepting the second or supplementary parts in two or three instances. These parts are nearly ready, and the manuscript for about half a dozen more volumes in regular succession has, in part or whole, been given to the printer.

A review of what has been done during the present term in the departments of photometry, spectroscopy and photography will be comprised in the next and closing number of this series.

VII.

Agreeably to the announcement of the annual report of Harvard College Observatory for 1877, as to photometry, a beginning was made by constructing a photometer suitable to be attached to the great telescope. Other photometers have been devised at different times for use independently. One of the earliest was applied during the year beginning Oct. 12, 1877, in measuring the light of all known satellites excepting the two inner ones of Uranus, which are too faint to be discerned, even by the great telecope. The first prolonged observation entered upon was of the eclipses of of Jupiter's satellites.

As there are four satellites and as the plane of their orbits is nearly the same as that of the planet itself, eclipses are frequent. The plan proposed the observation of all these eclipses visible during a revolution of Jupiter around the sun, a period of about 12 years. The work was begun June 23, 1878, and has been regularly pursued. The final result will be of the highest value in that, among its utilities it will permit a new and independent computation to be made of the earth's distance from the sun, which distance is a prime factor in theoretical astronomy.

Computations hitherto made, based upon data derived from these eclipses, are not authoritative, because of disagreements among different observers using different telescopes, and because of defects in the method of observation.

The director's report for 1878 says: "Errors of this kind are much lessened by photometric observations of the satellites as they gradually enter or emerge from the shadow of Jupiter, using the planet itself or another satellite as a standard. Each comparison thus obtained gives an independent determination of the time of the eclipse, free from the errors due to the condition of the air or the power of the telescope employed and less likely to be affected by personal equation than the observation of a disappearance or a reappearance. By the ordinary method an observation during twilight can have little value, while good photometric observations may be made as well then as at any other time. It is even possible to make them before sunset."

In 1879 a work of magnitude was begun—the photometric observation of all stars down to those of the sixth magnitude visible in this latitude. For greater facility, and particularly to avoid loss of time in identifying stars of small magnitude, it was decided to make a new departure in method and in construction of an instrument. The new instrument was called the meridian photometer, and stars were observed by it only when near the meridian. The position of any star being well known, the time of its appearance in the field of the telescope could be foreseen.

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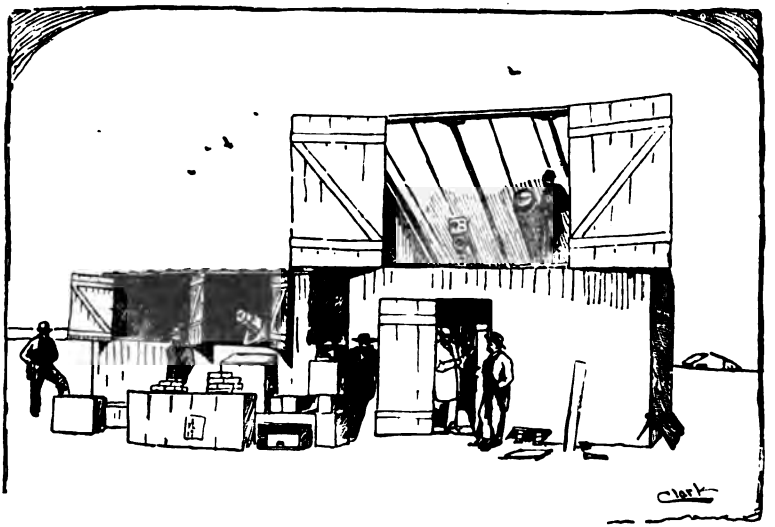
Each that was desired for a particular night had, therefore, only to be waited for, not sought for. The original instrument consisted of a fixed horizontal telescope pointed west and having two objectives.

The light of the pole star, which was taken for the standard or unit of measurement, was reflected by a prism into one object glass, and that of the star to be measured into the other. The light of the brighter star was then reduced to exactly that of the fainter by the turning

sive, between 30° south and the southern pole, was begun. Thus the facts relating to all the stars in the sky of these classifications will be embodied in the final result.

The record, which will comprise several volumes, one or more of which have already been published, will have an identity throughout as respects the method, the instrument, and the unit of measurement. It will be authoritative as a text book or series of text books, and will enhance the value for reference,



HARVARD OBSERVING STATION AT WILLOWS, CAL., JANUARY 1, 1889.

of a screw having a register attached. The indication of the register gave the measure, which was confirmed by repeated observations. Telescopes mounted in the ordinary way continued to be used in other branches of photometric work.

The photometric survey of the sixth magnitude and brighter stars was completed Aug. 25, 1881. In 1882 a new and more powerful meridian instrument was constructed and a photometric survey of a list of about 21,000 stars, from the sixth to the ninth magnitude, was entered upon. This work was finished Sept. 29, 1888, and soon afterwards the instrument, with others, was sent to Peru in charge of Mr. S. I. Bailey of the observatory corps, where, May 11, 1889, a corresponding survey of the stars, from the first to the ninth magnitude, inclu-

and comparison of various records of the light of stars, both those of modern and ancient date.

The successful working of the two meridian photometers led to the construction of one still more powerful, having an aperture of 12 inches. The first was of 1½ inch aperture, and the second of four inches.

The three differ somewhat in mechanism, but are the same in principle. The 12-inch is called by distinction the "horizontal telescope." It will be available in case a photometric survey of stars of fainter magnitudes shall be undertaken, but its use is not limited to photometry.

In 1879, a photometer was devised for measuring the light of nebulæ, thus applying to these objects and to stars the same unit and scale. In 1881, photo-

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metric observations of certain bright parts of the moon, were made for the Selenographical Society of England, the particular parts being selected by that society. It thus was shown that the lunar scale of light in common use may be closely expressed in terms of stellar magnitude, each degree of the lunar scale answering to six-tenths of a magnitude. Photometry has been very extensively applied at Harvard in study of variable stars.

A history of any department of practical astronomy, written from the point of view of a mechanician, could hardly fail to be of interest. Among the curious experiences at Harvard in the line of photometry is one which illustrates this point, and, at the same time, indicates the refinements in observation which are resorted to, and demonstrates one of the utilities of the photometric method.

HARVARD OBSERVING STATION IN PERU.

In 1877 announcement was made of the discovery at Washington of two satellites of the planet Mars. The Harvard telescope being applied they were after a little effort descried as two faint points of light, showing no visible disks. To ascertain the diameter of each satellite might therefore seem impossible: but it was done, approximately, by the photometric method.

The mechanical problem was to reduce the light of the planet as seen in the telescope to an equality with the light of one of the satellites as thus seen. Five or six different mechanics were employed to drill in a piece of metal a hole, making a true circle, and small enough to produce the equality sought for by sufficiently diminishing the light of the planet. It may be remarked that one of those who succeeded best had already, for his own purposes, managed to drill a hole, lengthwise, through a fine cambric needle, making a steel tube of it.

What he made for Prof. Pickering was a hole in a steel plate, the diameter of which was one eighteen hundredth (1-1800) of an inch. It was so nearly circular that the various diameters, including errors of measurement, only differed one one hundred thousandth (1-100,000) of an inch.

Other mechanical devices were resorted to for corroboration, and the results reached were that the diameter of one of the satellites is about six miles, and that of the other about seven miles. They are the smallest known in the solar system.

The availability of the spectroscope in astronomy had early been appreciated by the profession. In experiments in this line it had been found that a classification of the nebulæ might be made upon the basis of their spectra. In 1880 the study was carried a stage further at Harvard in ascertaining by the spectroscope that certain faint objects, which,

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by direct vision, had been judged to be stars, are in fact nebulæ. In 1881, it was found that the spectroscope is serviceable in the discovery of variable stars. Thus incited, a new instrument was imported from London, but it did not prove satisfactory.

Nothing of importance appears to have been done in this department thereafter until 1886, when the proposition of Mrs. Draper opened the way to investigation of spectra by aid of photography. For this the 11-inch photographic telescope, which had been used by Dr. Draper, was loaned by Mrs. Draper, who also met the expense of a new mounting and a special observatory building. A beginning was made with an eight-inch instrument, known as the Bache telescope. It is of the pattern described as the "doublet," and offers the advantage of a large field of view. With it the spectra of about 10,500 stars of the sixth magnitude and brighter, between the pole and 25° south, were photographed before the close of the year 1888.

The instrument was then sent to Peru, where a like survey of the Southern sky is in progress. Spectroscopic observations of the brighter stars have been continued at Cambridge with the 11-inch Draper telescope and of fainter stars with an 8-inch doublet similar to the Bache instrument. In this work it was found that by giving a certain chemical stain to the photographic plate the yellow and green portions of the spectrum of even the fainter stars can profitably be studied.

Furthermore, what seems incredible at first thought, it appears to be demonstrated that the components of binary stars whose juxtaposition does not permit them to be separated in any telescope, may, by spectroscopic photography, be shown to be in revolution about each other. Two or more such objects have been found in which the changes regularly succeeding in the lines of the spectrum not only prove that the components are in motion, but permit the period of revolution to be determined.

Prior to 1883 photography is mentioned in the annual reports of the present director only as incidental to other work. In that year a systematic investigation was undertaken, having among other objects in view, the construction of a photographic map of the whole heavens. An early application of photography in this investigation was in the direction of determining the color of stars, measuring their brightness by an independent method, picturing their spectra, exhibiting the effect of atmospheric absorption of light in a series of plates covering the period of a year, and ascertaining by images of stars trailed upon the plate, the clearness and steadiness of the atmosphere.

In 1887 the Boyden fund being available, the first step was taken in the important enterprise of giving a continental expansion to the work of the observatory. The aim of the testator in making his bequest could well be furthered in conducting observations simultaneously in photometry, spectroscopy and photography. In following up the project, the Draper memorial funds appear also to have been available to a considerable extent in the two latter methods of observation. Experimental stations were established in Colorado in the summer of 1887 on mountain peaks of 14,000, 11,000 and 6000 feet in height, respectively, and the meteorological conditions, including the transparency and steadiness of the upper atmosphere, were duly tested.

This investigation was continued at the expense of the Boyden fund during the following winter by local observers whose stations were at considerable height.

In 1889 the movement was further extended by establishing an observatory on a peak about 6500 feet high in Peru, 25 or 30 miles distant from the sea coast and the city of Lima. Local official sanction was given to naming the peak, "Monte Harvard." About the same time other observers of the Harvard corps set up an experimental observatory on Mt. Wilson, 6000 feet high, in Southern California. The station is about 30 miles from the sea coast and somewhat less from the city of Los Angeles.

The experimental purpose is the same as in Colorado, and looks to the ultimate establishment of a permanent observatory as a branch of the Harvard institution at some favorable point where the superior atmospheric conditions of the Pacific mountain regions can be had. In the special direction of picturing celestial objects at Mt. Wilson remarkable photographic results are already possessed at Cambridge in plates showing

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lunar surfaces, Saturn's rings, Jupiter's belts and the most brilliant of the nebulæ. That among them which is of the greatest scientific interest, as being a novelty, is the picture on a negative plate of the great spiral nebula of Orion. It is a Harvard discovery by the photographic method, and is quite other than that heretofore known as the great nebula in Orion. That is an object having a span of about half a degree. The new great nebula has a span of nearly 17 degrees; its outline includes all the stars of the constellation, and it is too faint an object to be discerned by the naked eye.

It is one of the principal advantages of the photographic method in astronomical work that the sensitive plate will denote objects which the eye reinforced by a telescope of any power cannot detect. The great nebula thus discovered is within reach of the telescope, but its dimensions are so much larger than the field of the telescope, and its outline so faint, that its true character would not thus originally be apprehended.

Photography at Cambridge has already produced several series of plates, each plate covering a section of the northern sky, the whole of which when perfected and collated will be a self-recorded, and so, indisputable atlas, showing the position of all stars down to those of the 11th magnitude. It will be an atlas in sheets of glass, and frailer in some respects than if composed of sheets of paper. But for study of the science the glass is better than any product of the engraver's art, and better than any sun picture printed by the plate itself. Indeed, it is one of the triumphs of the photographic method that a perfect photographic negative discloses more to the student than does a telescopic view of that area of the sky of which the photograph is a copy. Astronomical research is now constantly made at the observatory in this manner, and with results equal to or better than those reached by former methods.

Celestial objects are thus originally discovered and the positions of familiar objects remeasured or otherwise compared, and this work might be continued throughout the whole 24 hours were it so desired, regardless of the glare of the sun by day or of impenetrable clouds by night.

The work in progress in Peru will give other series of plates offering equal facilities for the study at Cambridge of that part of the sky which is beyond our southern horizon. Some of the results which these extensive investigations of the light, the spectra and the positions of the stars will yield will anticipate the doings of other great observatories of the world. But there is no necessary limit at stars of the magnitudes named; there will remain other worlds to conquer

A special encouragement to new enterprises at Harvard is in the munificent gift of $50,000, made within the year past by Miss Catherine W. Bruce of New York for the construction of a telescope of 24 inches aperture, to be used in photography. A contract for this instrument has been made. It is intended that its first use shall be to photograph maps of the fainter stars, and it is hoped that those as faint as the 16th magnitude can thus be represented. The basis of this sanguine forecast is the fact that with an eight-inch telescope of the pattern of the proposed 24-inch, and an exposure of the plate for one hour, twice as many stars are photographed as are visible with a telescope of 15 inches aperture. Prof. Pickering received the honorary degree of A.M. from Harvard in 1880, and that of LL.D. from the University of California in 1886, and from the University of Michigan in 1887. Like his predecessor, Prof. G. P. Bond, he has been honored by the Royal Astronomical Society in the bestowal of its gold medal.

The several investigations of chief importance which are now in progress at Harvard College Observatory have already been mentioned as part of the record of the half-century past. They also go into the record with which the second half-century now begins. As such they may be briefly recapitulated, viz.: The survey, for the purposes of the great European standard catalogue known as the "Astronomische Gesellschaft," of the zone between 9° 50′ south and 14° 10′ south; the photometric, spectroscopic, and photographic special surveys making in south latitude to complete like surveys hitherto made at Cambridge, extending to about 30° south; the systematic work in photography, which includes much classifiable as spectroscopy, carried on both at Cambridge and in Peru as the Draper Memorial work; other systematic work of like importance done under the special restrictions of

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the Boyden fund; and what perhaps may be called the orbital observations of eclipses of Jupiter's satellites.

That planet has now nearly completed its circuit around the sun, and the last of its satellite eclipses to be observed will occur on Dec. 17 ensuing. During the period of 12 years about 450 of these eclipses have been observed and recorded. Perhaps as many others for which preparations were made at the observatory, passed unseen, because of interposing clouds. Except to an expert these figures give no hint of the magnitude of the work. All that need here be said is that in its completed form it will be one of the great achievements of the observatory.

The enumeration of these unfinished works and those completed, which has now been made, will have fulfilled its purpose if it shall have impressed upon the mind of the general reader the fact, with which it is presumable everybody is somewhat familiar, that a great oak has grown from the little acorn planted on Harvard College campus 50 years ago.

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FORTY-FIFTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING OCTOBER 31, 1890.

BY

EDWARD C. PICKERING.

CAMBRIDGE, MASS.
PUBLISHED BY THE UNIVERSITY.
1890.

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REPORT.

To the President of the University:

Sir, — The urgent need at the Observatory of a fire-proof building has been pointed out in several successive annual reports. The last year has brought to the Observatory about nine thousand photographic plates, — some taken in Peru, some in California, and some in Cambridge. The total number of these plates is about twenty-seven thousand. All of them are stored in wooden buildings, where they might be destroyed by fire in a few minutes. They represent nearly the entire sky from the north to the south pole, the greater portion being covered several times, and they show not only the positions of the stars, but also their spectra. A large part of the charts and nearly all of the spectra are unique and have not been photographed elsewhere. Accordingly, in case of fire, future astronomers wishing to study changes in the stars would be obliged to begin with 1891 instead of being able to carry their work back in many cases to 1885. Even the weight of the plates is becoming a source of danger to the main building of the Observatory, as its floors are not constructed to carry heavy loads. Besides the photographs, a large amount of original manuscript, representing observations extending over a dozen years, is liable to destruction. This danger would be avoided by publication in the case of the manuscripts, but only partially in the case of the photographs. Accordingly excellent progress in publishing has been made during the last two years. But even here we are stopped by the expense and are obliged to delay until the interest of the publishing funds has accumulated. Otherwise, several additional volumes could be at once undertaken. The library is one of the most extensive and complete in astronomical works in the United States, and if destroyed could not be easily replaced. Finally, the instruments are delicate and valuable, although representing a small sum compared with the photographs and manuscripts.

In the last annual report reference was made to the loss sustained by the Observatory of one of its oldest friends, Mr. J. I. Bowditch. Since then I have learned that to his many gifts to the Observatory he has added another, — a legacy of twenty-five hundred dollars.

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Observatory Instruments.

East Equatorial. — The observations made during the year are as follows: 21 eclipses of Jupiter's satellites have been photometrically observed, making in all 451 since 1877. The following comets have been observed for position: 1889 I. on 1 date; 1889 V. on 31, comprising 34 observations; companion to 1889 V. on 3; 1889 VI. on 7; 1890 I. on 3; the comet discovered by Brooks, March 19, on 12 dates; the comet discovered by Coggia, July 18, on 4 dates; the comet discovered by Denning, July 23, on 2 dates; and D'Arrest's comet, rediscovered by Barnard on October 6, on 1 date. The systematic observation of 17 circumpolar variables has been continued, as in the previous year, and one recently discovered by photography has also been added to the list. Each star is observed about once in two weeks by the Argelander method and by direct estimation of magnitudes. The total number of these observations during the last year is 381 relative estimates by the Argelander method and also the same number of estimates of magnitude, with the large telescope. Relative estimates of these variables were obtained at the same time with the finder, if the stars were visible in it; 37 series of relative estimates of comparison stars for these variables have also been made, and 10 series of photometric measurements of the same stars with the wedge photometer. The wedge photometer has likewise been used in the observation of 22 series of zones from the Durchmusterung, comprising 838 stars.

In order to facilitate the decision of questions relating to the identity of stars observed with the meridian circle in the zone $+50°$ to $+55°$, 70 observations of the relative positions of stars have been made with the Equatorial. In addition to the above, observations have been made of several other miscellaneous objects. These observations, except those of Jupiter's satellites, have been made by Mr. Wendell.

Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision. The printing of the zone catalogue, as shown under the head of Publications, is far advanced. The manuscript of the volume which is to contain the separate results of previous observations of the stars of the Harvard College zone reduced to 1875.0, with a discussion of the systematic errors involved in the reduction to the system of the Astronomische Gesellschaft of the various catalogues employed, together with the resulting proper motions, is ready for the printer. The time required in preparing this volume has

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allowed little progress to be made in the reduction of the observations made from 1879 to 1883.

The observation of the southern zone comprising the declinations from —9° 50′ to —14° 10′ has been continued throughout the year by Professor Searle, assisted by Mr. Dunne. The number of nights of observation is 111; the total number of observations is 6955, distributed as follows: 214 relating to circumpolar stars, 777 to fundamental stars, 5768 to zone stars, 70 to variable stars, and 126 to stars incidentally observed. Continuous progress has been made in the reductions, and forms have been arranged for the publication of the observations. A few series of observations have been entered in these forms.

West Equatorial. — The six-inch equatorial mounted in the West Dome has been used in testing the new method proposed by Professor Michelson for measuring double stars by means of diffraction images. Mr. W. M. Reed has also used it in an investigation of the light curves of variables of long period. A large part of the work has been done during the last month, but in all 218 observations have been obtained on 40 nights.

Henry Draper Memorial.

During the past year 1309 photographs have been taken with the Bache telescope at the station near Chosica in Peru. Nearly all of them relate to the region south of —20°. Photographic charts having an exposure of ten minutes and showing all stars to the twelfth magnitude have been obtained, comprising nearly the entire region. Charts with an exposure of sixty minutes, showing stars to the fourteenth magnitude, cover about one half of the region. Spectra with an exposure of ten minutes, including stars of the sixth magnitude, cover nearly the entire region; and spectra with an exposure of sixty minutes, including stars of the eighth magnitude, cover about one half of the same region.

An instrument like the Bache telescope, having a photographic doublet for an objective, is capable of collecting so large an amount of useful material that Mrs. Draper decided to have constructed a second instrument of the same dimensions. This was accordingly mounted on the Observatory grounds and has been kept at work every clear night until daybreak since September 27, 1889. 2157 photographs have so far been taken, including charts with exposures of ten minutes, covering the sky north of —20°. By placing over the objective a prism of small angle, the spectra of very faint stars have been obtained even when they were as faint as the tenth magnitude.

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Even red stars can be photographed in this way, and many objects having peculiar spectra now come within the reach of photography. Thus twenty-nine spectra of the fourth type have been obtained of which six, namely, DM. +14° 2048, A. G. C. 16937, 18947, 20554, 29232, and 30526 (π Gruis), are new. The variable star U Hydrae belongs to this class. Spectra of fifteen planetary nebulae have been photographed. The hydrogen line, F, has been shown to be bright in eight stars, δ Centauri, μ Centauri, η Centauri, H. P. 1124, 3747, A. G. C. 17717, 18859, and χ Ophiuchi; the last has also other bright lines. Photographs have been obtained of all of the stars known to belong to that remarkable class discovered by Rayet, in which the spectrum consists mainly of bright lines. They number twenty-eight, and thirteen of them have been discovered in the present investigation, three during the past year. Their photographic spectra generally resemble closely those of the planetary nebulae. The hydrogen lines are shown to be bright in thirty variable stars of long period, namely: R Andromedae, o Ceti, U Ceti, R Tauri, R Aurigae, U Orionis, R Lyncis, L_2 Puppis, R Carinae, S Hydrae, R Leonis, R Ursae Majoris, R Corvi, T Ursae Majoris, R Virginis, S Ursae Majoris, U Virginis, R Hydrae, S Virginis, R Camelopardalis, R Bootis, S Coronae, U Herculis, R Draconis, R Ophiuchi, T Herculis, χ Cygni, T Cephei, R Aquarii, and R Cassiopeiae. This peculiarity of the variable stars furnishes a means of discovering them. Seven new variable stars have been found in this way, namely: DM. +48° 2942, DM. +33° 470, A. G. C. 18770, A. G. C. 22855, and the stars whose approximate positions for 1900 are in R. A. $1^h.55.1^m.$, Dec. +56° 15′, R. A. $4^h.37.1^m.$, Dec. −38° 26′, and R. A. $20^h.9.4^m.$, Dec. −39° 29′.

The photographic charts mentioned above generally permitted the variability of these objects to be confirmed at once without waiting for confirmation visually. Every year, by the accumulation of additional photographs, this can be done more readily. Besides these stars about forty other stars have been suspected of variability owing to their spectra, and photographs of the regions containing them are taken every few days. A careful examination is made by Mrs. Fleming of all the photographs taken with the eight-inch telescopes in Cambridge and Peru, and has led to the discovery of about a hundred new third-type stars besides the objects named above. Mrs. Fleming has also had charge of the computation involved in Volumes XXVI. and XXVII. described below, and has prepared a large part of them for the press.

The detailed study of the spectra of the brighter stars with the eleven-inch telescope has been continued. Photographs have now

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been obtained, 845 during the past year, of nearly all the stars visible in this latitude and sufficiently bright. A beginning has been made of the description of these spectra. The most interesting result has been the discovery by Miss Maury of a second star, β Aurigae, which is shown by the doubling of the lines in its spectrum at regular intervals to be a close binary. The period of revolution in this case is very nearly four days. 78 photographs have been obtained of the spectrum of this star, and 89 of ζ Ursae Majoris. Two of the large prisms have also been attached to the fifteen-inch equatorial, and 143 photographs of the spectrum of ζ Ursae Majoris and 26 of β Aurigae have been taken with this instrument during the morning hours after its use for visual purposes is over. One photograph of σ Herculis seemed to show that this star also was double, but it has not been confirmed, although numerous additional photographs have been secured. Some interesting photographs have been obtained of the spectrum of several metals in the Bunsen flame. A photographic determination of the position of the pole of the heavens was made by Mr. R. D. Upham with the fifteen-inch Draper reflector. This apparently furnishes a means of measuring precession and nutation directly.

Boyden Fund.

Work under this fund has been continued at three places: Harvard College Observatory, Wilson's Peak in Southern California, and Chosica in Peru. Professor William H. Pickering took immediate charge of the work at the Observatory. Much time was devoted to visual observations of the colors and markings of the planet Mars with the twelve-inch telescope. A number of the so-called canals were recognized, but only one of them was distinctly seen to be double. The best methods of photographic enlargement of astronomical objects have also been studied. Investigations, founded on observations made here and elsewhere, have been conducted with regard — first, to the meteorology of the globe, with particular reference to cloudiness and other phenomena affecting the choice of astronomical stations; secondly, to the fundamental principles of astronomical photography; thirdly, to the great nebulous region comprising a large part of the constellation Orion; fourthly, to the best form of standard light; and finally to other details of quantitative photometric work. As will be seen from the list of publications, portions of these investigations have appeared in various periodicals. Instruments and buildings have been planned and largely constructed for future use at Arequipa, Peru.

The station at Wilson's Peak was kept in operation until August,

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when the telescope was dismounted and sent to Cambridge to be transmitted to Peru. The advantages of the climate of Wilson's Peak are less marked than was anticipated; still, they have been sufficient to justify an attempt to purchase a suitable site there for a more permanent station. This attempt has not yet succeeded owing to uncertainties of title and other difficulties. If it should fail, other equally good locations in the same region can be secured. The photographs taken at Wilson's Peak have largely represented the Moon and the planets, particularly Mars, the more conspicuous permanent markings of this planet having been successfully photographed. An important accession to the white spot surrounding the southern pole was found by the photographs to have occurred between the nights of April 9 and 10. One of the most interesting discoveries has been that of the immense extent of the great nebulous region of Orion; many interesting photographs of double stars and clusters have also been obtained.

Good progress was made at the station near Chosica in Peru, maintained by the Draper and Boyden departments conjointly, until the approach of the cloudy season. The clouds gradually rose higher and higher until they covered the observatory. Accordingly, in November, 1889, the Messrs. Bailey visited various points along the coast, going as far south as Valparaiso, and passing some time in Pampa Central in the desert of Atacama, one of the driest points on the surface of the earth. Their observations led to the conclusion that no better place could be found than Arequipa, situated on the Mollendo railway, at an elevation of about eight thousand feet. It did not seem best to make the change until the clear season was over. They accordingly returned to Chosica and resumed work there until October, 1890, when the instruments were dismounted, and it is expected that observations will be continued early in November at Arequipa.

The observations of the southern stars with the meridian photometer are now approaching completion. 110 series, comprising 13,836 stars (including duplicates), have been observed. The number of photometric settings is 55,344.

Valuable aid was rendered to the expedition by various residents in Peru, especially by Hon. John Hicks, United States Minister to Peru, and by Señor J. L. de Romaña, of Arequipa, under whose supervision a very instructive series of meteorological observations was carried on at four stations: Mollendo, at the sea level; Arequipa, at the elevation of 7500 feet; Vincocaya, at the elevation of 14,600 feet; and Puno, at the elevation of 12,500 feet.

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The Bruce Photographic Telescope.

The disks of glass for the lenses of this instrument have not yet been received. The disk for the prism, which is twenty-five inches in diameter and three inches thick, arrived safely. It appears to be unusually free from defects and nearly colorless. The important gift by Miss Bruce of six thousand dollars, to be distributed among astronomers of all nations, should be mentioned here. It furnishes an example of using money so as to secure the greatest scientific return, which, it is hoped, will find many imitators.

Miscellaneous.

Library. — The library of the Observatory has been increased during the year by the addition of 311 volumes and 856 pamphlets. The total number of volumes and pamphlets on November 1, 1890, were respectively 6767 and 6891.

Time Service. — The standard time signals have been sent mainly by the Bond clock No. 394. The errors have been abnormally large this year. Their average at the time of observing star transits has been 0.42, the average interval between determinations being 2.4 days. The average error at 10 A.M. has been 0.37, the number of clock comparisons being about 700. The average change in the daily rate from each day to the next has been 0.38. On July 25, however, the error was uncertain for several hours on account of a defective performance of the Ballou clock No. 103, which was then sending the signals; and on February 19 no signals were sent on account of damage to the transmitting apparatus by lightning on the previous evening. A line following a new route near Harvard Square has improved the transmission of the signals.

The Boston Time Ball was dropped on 286 week days automatically by telegraph at noon. On two other occasions it started prematurely, but was immediately rehoisted, as a signal of incorrect dropping, and then slowly lowered.

Telegraphic Announcements. — The distribution of telegraphic announcements of discovery has been continued under the management of Mr. Ritchie. During the year telegrams concerning the discovery of eleven asteroids and five comets, and others relating to three orbits and to two positions of comets, have been sent out, requiring in all 278 telegrams and 14 cable messages.

Publications. — The printing of the zone catalogue of stars between the declinations +55° 10′ and +49° 50′ has proceeded as far as the

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right ascension 17^h, and, at the present rate of progress, should be finished in about six weeks. This catalogue forms the chief part of Volume XV., Part II., of the Annals of the Observatory. Volume XVIII. was completed during the year by the publication and distribution of its final section, No. X. This contains a discussion of meridian circle observations of stars near the south pole. The first portion of Volume XIX., Part II., is in type. It consists of a discussion of the zodiacal light by means of the observations made here during the last fifty years. Volume XXI., Part I., and Volume XXII., mentioned last year as nearly complete, were published during the year. These works contain the observations of the New England Meteorological Society for 1888 and the observations made on Pike's Peak by the United States Signal Service, 1874 to 1888. Volume XXI., Part II., will be published immediately. It contains the observations of the New England Meteorological Society for 1889, with essays by officers of the Society on climate and sea breezes. Of Volume XXIII., Part I., 121 pages are in type. This part contains a description of the observations with the meridian photometer in the years 1882 to 1888, inclusive. The printing of Volume XXIV. is completed. It contains the determinations obtained with the large meridian photometer of the brightness of stars from the Durchmusterung, and of a considerable number of miscellaneous stars. The total number of stars measured in this work is 20,982. Volume XXV. is not yet undertaken. Volume XXVI., Part I., is in type to page 138. It contains a description and discussion of the observations made with the Bache telescope during the years 1885 to 1889. The printing of Volume XXVII. is completed. It forms part of the Henry Draper Memorial, and contains a catalogue of the spectra of 10,347 stars, to be known as the Draper Catalogue. Volume XXX., Part I., which is also completed, forms a continuation of Volume XX., and contains meteorological observations made at the Blue Hill Observatory during the year 1889.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-fourth Annual Report of the Astronomical Observatory of Harvard College. Cambridge, 1890.

Henry Draper Memorial. Fourth Annual Report of the Photographic Study of Stellar Spectra conducted at the Harvard College Observatory. Edward C. Pickering, Director. Cambridge, 1890. Reprinted in the Memorie della Società degli Spettroscopisti Italiani, xix. 88.

Circular on Aid to Astronomical Research. By Edward C. Pickering. Reprinted in Nature, xlii. 299; The Observatory, xiii. 286; Sidereal Messenger, ix. 329.

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Observations of the Zodiacal Light made at Harvard College Observatory. By Arthur Searle. Astronomische Nachrichten, cxxiv. 405.

Comparison of Photographic Efficiency of Telescopes. By W. H. Pickering. Knowledge, xiii. 35.

The Great Nebula in Orion. By W. H. Pickering. Sidereal Messenger, ix. 1.

The Occultation of Jupiter, Sept. 3, 1889. By W. H. Pickering. Ibid. ix. 148.

Photographs of the Surface of Mars. By W. H. Pickering. Ibid. ix. 254.

Visual Observation of the Surface of Mars. By W. H. Pickering. Ibid. ix. 369.

Use of the Swing-back versus the Sliding-front. By W. H. Pickering. Anthony's International Photographic Annual, 1890, p. 252.

Comets of 1887–8. By O. C. Wendell. Sidereal Messenger, ix. 38.

Orbit of Comet 1890 I. By O. C. Wendell. Sidereal Messenger, ix. 89.

Observations of Comets 1887 V., 1888 V., and 1889 I. By O. C. Wendell. Astronomische Nachrichten cxxiii. 295; also, Astronomical Journal, ix. 91.

Transit of Comet 1889 V. over a star. By O. C. Wendell. Sidereal Messenger, ix. 134.

Observations of Comets 1889 VI. and 1890 I. By O. C. Wendell. Astronomische Nachrichten, cxxiv. 113; also, Astronomical Journal, ix. 159.

An approximate solution of Euler's Equation for Parabolic Motion. By O. C. Wendell. Sidereal Messenger, ix. 176.

Observations of Comet 1886 VII. By O. C. Wendell. Astronomische Nachrichten, cxxiv. 363; also Astronomical Journal, ix. 191.

Observations of Comets 1889 I., 1889 V., Companion to 1889 V., Comet a 1890, Comet b 1890, and Comet c 1890. By O. C. Wendell. Astronomical Journal, x. 69.

Ephemeris of Comet a 1890. By O. C. Wendell. Sidereal Messenger, ix. 276.

Elements and Ephemeris of Comet a 1890. By O. C. Wendell. Sidereal Messenger, ix. 324.

Ephemeris of Comet c 1890, for October, 1890. By O. C. Wendell. Sidereal Messenger, ix. 374.

Spectra of δ and μ Centauri. By M. Fleming. Astronomische Nachrichten, cxxiii. 383; also, Sidereal Messenger, ix. 91.

New Variable in Caelum. By M. Fleming. Astronomische Nachrichten, cxxiv. 175.

Stars having Peculiar Spectra. By M. Fleming. Ibid. cxxv. 155.

Two New Variable Stars near the Cluster 5 M Librae. By M. Fleming. Ibid. cxxv. 157.

New Variable Star in Scorpius. By M. Fleming. Ibid. cxxv. 361.

Stars having Peculiar Spectra. By M. Fleming. Ibid. cxxv. 363.

New Variable Star in Sagittarius. By M. Fleming. Ibid. cxxv. 365.

Stars having Peculiar Spectra. By M. Fleming. Sidereal Messenger, ix. 379.

Transit Observations in Photography. By W. P. Gerrish. Sidereal Messenger, ix. 121.

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A Simple Break Circuit for Clocks. By W. P. Gerrish. Sidereal Messenger, ix. 124.

On the Spectrum of ζ Ursae Majoris. By Edward C. Pickering. American Journal of Science, cxxxix. 46. Reprinted in The Observatory, xiii. 80; Sidereal Messenger, ix. 80.

New Variable Star in Cygnus. By Edward C. Pickering. Sidereal Messenger, ix. 232.

Sur les Résultats Photométriques auxquels peut conduire la Photographie Céleste. By Edward C. Pickering. Bulletin du Comité International Permanent pour l'exécution photographique de la Carte du Ciel, Cinquième Fascicule, p. 350. Paris, 1890.

Letter to Admiral Mouchez. By Edward C. Pickering. Ibid. p. 371.

A New Class of Binary Stars. By Edward C. Pickering. Monthly Notices of the Royal Astronomical Society, l. 296.

Southern Stars having Peculiar Spectra. By Edward C. Pickering. Astronomische Nachrichten, cxxiii. 95.

Spectrum of Pleione. By Edward C. Pickering. Ibid. cxxiii. 95.

Variable Stars in Cluster G.C. 3636. By Edward C. Pickering. Ibid. cxxiii. 207.

The Star $12^h.\ 18.0^m.$ —48° 43′ (1875.0). By Edward C. Pickering. Ibid. cxxiv. 21.

New Variable Star in Cygnus, DM. +48° 2942. By Edward C. Pickering. Ibid. cxxiv. 271.

A history of the Observatory from its foundation to the present time was recently published by Mr. Daniel W. Baker, of Boston, in a series of articles in the Boston Evening Traveller, and has been reprinted in pamphlet form.

By the kind assistance of Hon. Patrick Egan, United States Minister to Chili, a full description of the work of the Observatory in South America, prepared by Mr. M. H. Bailey, was published at Santiago on February 19, 1890, in El Ferrocarril, and at Valparaiso on the following day in El Mercurio.

EDWARD C. PICKERING, *Director*.

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FORTY-SIXTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING OCTOBER 31, 1891.

BY

EDWARD C. PICKERING.

CAMBRIDGE, MASS.
PUBLISHED BY THE UNIVERSITY.
1891.

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REPORT.

To the President of the University: —

Sir, — For several years past the Observatory has needed a fire-proof building for preserving the large collection of photographs contained in the West Wing. This collection consists of nearly thirty thousand glass plates representing the entire sky from the north to the south pole, partly taken in Cambridge and partly in Peru; also a similar collection of the spectra of the stars, and of spectra on a much larger scale of the bright stars visible in Cambridge. These photographs show the condition of the sky from 1886 to the present time and form the only collection of the kind which exists. The building in which they are stored is of wood and if a fire broke out would be destroyed in a few minutes. Fortunately, there is now a prospect that this want may be supplied by the erection of a plain brick structure. Subscriptions to the amount of $7200 have been promised towards a fund of $10,000 which is the estimated cost of the required building.

It is hoped that the remaining $2800 can be secured before long and that the foundation can be laid early next spring, so as to protect the plates from danger at as early a date as possible.

Observatory Instruments.

East Equatorial. — The observations with this instrument have been partly photometric and partly micrometric. Twenty eclipses of Jupiter's satellites have been observed photometrically, making 471 since 1877. One of the eclipses observed this year belongs to the opposition of 1890–1891 and completes a series of 452 eclipses observed during a period of rather more than one revolution of Jupiter. This series will be separately reduced and published. The systematic observation of seventeen circumpolar variable stars of long period has been continued, as in last year. Special attention was paid to the stars when they were faint. The relative brightness of the stars was determined by Argelander's method and a direct estimation was also made in each case. The total number of observations is 560 by each of these methods. Relative estimates of brightness were also made with the finder when the star was not too faint. Seventy series of observations of the relative brightness of the comparison stars for these variables were made, and fourteen series of

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measurements with the wedge photometer. Twelve zones comprising 403 of the fainter stars contained in the Durchmusterung were observed with the same instrument, each star being measured three times. Besides other miscellaneous observations, micrometric measures have been made of the positions of all the fainter comparison stars of the circumpolar variables and of the following comets: Comet 1891 IV. on 7 dates; 1891 a on 3 dates; 1884 III. on 6 dates; 1891 d on 8 dates. All of the observations, except a part of those of Jupiter's satellites, have been made by Mr. Wendell.

Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision. The printing of the zone catalogue, as shown under the head of Publications, is completed, and the manuscript of the introduction to that catalogue is in the hands of the printer. The manuscript of three additional volumes, each of about 400 pages, has been prepared. Two of these volumes contain the journal of the zone observations, and the third contains the reduction to 1875.0 of all previous observations available for comparison with the zone catalogue, and a discussion of the results thus obtained for proper motion.

The observation of the southern zone comprising the declinations from —9° 50′ to —14° 10′ has been continued throughout the year by Professor Searle, assisted by Mr. Dunne. The number of nights of observation is 130; the total number of observations is 6220, distributed as follows: 255 relating to circumpolar stars, 853 to fundamental stars, 5080 to zone stars, 29 to variable stars, and 3 to stars incidentally observed. It appears probable that continuous observation will be unnecessary after April, 1892, as nearly all the zone stars will then have been observed twice, and many of them three times, if the work continues through the winter without interruption. The reductions have been regularly continued and provisional results have been obtained for the stars observed in the summers of 1888 and 1889.

West Equatorial. — Observations have been made with the six-inch equatorial mounted in the West Dome on 148 nights by Mr. W. M. Reed. The principal work has been the study by Argelander's method of the changes in the light of the variable stars of long period. 668 observations have been made of the 17 circumpolar variables mentioned above, 98 of other variables of long period, 245 of variables of short period, and 61 of new variables. About 840 comparison stars have been selected for 42 variables. Another important investigation has been on the use of a small prism attached to the centre of the object-glass. Each star is thus accompanied by an image about

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four magnitudes fainter than itself by which it is expected that the scale of photometric magnitude may be extended from the eighth to the twelfth magnitude. The relative brightness of the two images has been determined by four independent methods.

Henry Draper Memorial.

Three telescopes have been used continuously in this department of the Observatory, generally throughout every clear night. The eight-inch telescope closely resembles the Bache telescope and has a photographic doublet for an objective. 2505 photographs have been taken with it this year. Nearly one-half of the northern sky has been covered with charts having an exposure of ten minutes. A small prism attached to the objective forms faint images of the brighter stars and provides a means of determining the true brightness of the fainter stars. A prism covering the objective enables the spectra of the fainter stars to be photographed. Similar work on the Southern stars has been done in Peru with the Bache telescope, 1224 photographs having been taken. The examination of these plates by Mrs. Fleming has shown that eight variable stars, R Cancri, S Serpentis, R Herculis, S Herculis, R Cygni, R Aquilae, and V Monocerotis, in addition to the thirty previously announced, have the hydrogen lines bright in their spectra. Five new variables have been discovered during the year by means of this property. Bright lines are also seen in the spectra of R Coronae and g Herculis which apparently are not due to hydrogen. Two known variables, R Sculptoris and U Cygni, have been shown to be of the fourth type and two fourth-type stars have been discovered to be variable. The number of stars of the fifth type, that is, having bright lines in their spectra like those discovered by Wolf and Rayet, has been increased by nine. The total number now known of these objects is 37, 27 of which have been found at this Observatory. All of them are situated very near the central line of the Milky Way which fact has led to the detection of several previously unknown. The hydrogen line F was shown to be bright in ν Sagittarii and ν Cygni. DM. —12° 1172, hitherto supposed to be a star, is shown by the photographs to be a planetary nebula. Two stars, DM. —10° 513 and DM. —10° 5057, have spectra of the fourth type in which, however, the blue light is well shown so that they do not have the usual characteristic red color. Well marked spiral rays are visible in a photograph of N. G. C. 1566.

The number of photographs taken with the eleven-inch Draper telescope is 1089. Photographs have now been obtained of the spectra of all the stars visible in Cambridge and bright enough to

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bear the dispersion used with this instrument. A large number of photographs were taken of β Aurigae to determine the form of the orbit of this curious binary. During December, 1890, this star was followed throughout every clear night so that the period could be determined with precision by comparison with similar observations made in 1889. By moving the telescope in right ascension every twenty minutes several spectra were obtained on each plate. In all, 184 spectra of this star were photographed. 106 photographs were also taken of ζ Ursae Majoris to study the apparent irregularity in the time at which its lines are double. In 10 cases only are the lines certainly double. An interesting discovery was made by Mrs. Fleming, that the bright lines in the spectrum of β Lyrae change their position in a manner somewhat like the doubling of the dark lines in β Aurigae. The changes occur in the same period as the changes in light and appear to be very complex, but could, in general, be explained if we suppose the star to be a close binary; the spectrum of one component having bright, — the other, dark lines. A careful study of these changes has been made by Miss Maury and also of the spectra of the stars of the Orion type. A large number of charts have also been made of the vicinity of variable stars and of other peculiar objects, so that the parallax can be detected, if appreciable. To permit the prisms to be easily removed and replaced they have been counterpoised with a system of link-work which permits these changes to be made almost instantly without disturbing the equilibrium of the telescope. A large amount of work has been done on the measurement of the position of the lines in the stellar spectra and their conversion into wave-lengths. By the kindness of Mr. Edison, a dynamo of four horse power has been presented to the Henry Draper Memorial. This will greatly facilitate the study of terrestial spectra.

Boyden Fund.

The attempt to secure a suitable location for an observing station on Wilson's Peak in Southern California proved unsuccessful. A clear title could not readily be obtained for the land and the advantage of the situation as regards climate proved to be less than was at first anticipated. Although the air is extremely steady at certain times, clouds prevent observations during a large part of the winter and in the daytime the unsteadiness of the air would interfere seriously with solar work.

The expedition sent to Peru in 1889 under the direction of Mr. S. I. Bailey, having successfully completed the observations with the meridian photometer, returned to Cambridge with that instrument, which

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has been remounted here and will be used for a revision of the Harvard Photometry and for other photometric work. During the two years ending May 1, 1891, Mr. Bailey took 217 series of observations and made 98,756 photometric comparisons of about eight thousand southern stars. These include all the stars of the sixth magnitude and brighter south of —30° and all known catalogue stars in a series of zones 20′ wide at intervals of 5° in declination from —25° to —80°; also all known stars south of —80° and a miscellaneous list of variables, stars having peculiar spectra, etc. The reduction of these observations is nearly completed and their publication will be begun shortly. A large part of the work assigned to the Bache telescope has also been completed, and the instrument has been remounted at Arequipa where its work will be continued.

An expedition under the direction of Professor William H. Pickering left Cambridge in December, 1890, and established a station about three miles northwest of Arequipa, where the thirteen-inch equatorial has been mounted. This station has an elevation of a little over 8000 feet and has a nearly cloudless sky during a large part of the year. The air is remarkably steady, the images of the stars are small and round and the diffraction rings, seldom seen with large instruments, are clearly visible. Even with high powers the fluctuations of the images is very slight. In fact, at this station the limit to observation will probably be the size of the instrument instead of, as at other observatories, the condition of the air. Although the aperture of this instrument is only thirteen inches, it appears to be the largest refracting telescope in use in the southern hemisphere, while about thirty larger telescopes are mounted in the northern hemisphere. Since all of these instruments are north of +35° nearly one quarter of the entire sky, and that containing many objects of the greatest interest, has never been studied by a refractor of the highest grade. For both these reasons an excellent opportunity is afforded to add to astronomical discovery by the erection of a telescope of large size at this station. It is hoped that patrons of astronomy will consider the advantages of erecting a large telescope where it will be kept constantly at work, where the sky is clear a large part of the year, where the condition of the air is probably more favorable than at any other existing observatory, and where a large part of the sky could be examined for the first time under such satisfactory conditions.

Photographs have not yet been obtained with the thirteen-inch telescope, but it is hoped that its advantages for this kind of work will be as great as for visual observations. The expense of establishing this station was much greater than had been anticipated, since it was necessary to erect a stone dwelling-house for the observers. A con-

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siderable advance from the future income of the fund has accordingly been required. Important aid was rendered to the expedition by many residents in Peru. Mr. MacCord, Superintendent of the Mollendo Railway, should be especially mentioned for his hospitality to the observers who resided with him while the new house was in process of erection. Without his aid the establishment of the station would have been extremely difficult. Two interesting expeditions have been made in Peru. One of them by the courtesy of Mr. Anderson, American Minister to Bolivia, was to Tiahuanuco and the sacred islands of the Incas on Lake Titicaca and led to results of much archaeological interest. The other was to the summit of El Misti, a nearly extinct volcano about nineteen thousand feet high.

The Bruce Photographic Telescope.

The two disks of glass for the flint-lenses of this instrument have reached here safely and appear to be of excellent quality. An accident to one of the disks of crown glass delayed its completion, but both of them are promised at an early date. Plans are being prepared for the mounting, and work on the instrument will begin as soon as the crown disks are received. The work of grinding and polishing the 24-inch prism to be used with this telescope has been completed during the year.

Various subsidiary investigations have been planned in connection with this instrument. For instance, the brightness of all stars photographed should be reducible to a uniform scale of magnitudes. A photographic transit instrument has been constructed which is moved automatically and photographs on a single plate all stars brighter than the sixth magnitude which cross the meridian during three hours. With this instrument it is expected to prepare a catalogue like the Harvard Photometry which will give the photographic magnitude of the bright stars on a uniform scale. A second investigation now well advanced will give the brightness upon the same scale of about forty thousand stars of the tenth magnitude. These stars are distributed throughout the entire sky so that one is in each square degree. Nearly three thousand of these stars have already been selected and almost all of them measured. About an equal number of brighter stars serves to reduce these observations to the same scale of magnitudes. Suitable photographs have been obtained of about one quarter of the entire sky, the whole of which will be photographed twice.

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Miscellaneous.

Library. — The library of the Observatory has been increased during the year by the addition of 262 volumes and 821 pamphlets. The total numbers of volumes and pamphlets on November 1, 1891, were respectively 7029 and 7781.

Time Service. — The standard time signals have been sent mainly by the Bond clock No. 394. The average error at the time of observing star transits has been 0.44, the average interval between determinations being 2.5 days. The average error at 10 A.M. has been 0.38, the number of clock comparisons being about 500. The average change in the daily rate from each day to the next has been 0.32. In computing these figures the results for September 11 have been omitted since a large error occurred on that day owing to an accident to the clock. The signals were interrupted from September 14 to 17 owing to changes in the cable at the draw of West Boston Bridge. The Time Ball dropped correctly on 285 week days. It is probable that this department of the work of the Observatory will be abandoned shortly since similar signals furnished by the U. S. Naval Observatory are now offered to the public through the Western Union Telegraph Company.

Telegraphic Announcements. — The distribution of telegraphic announcements of discovery has been continued under the management of Mr. Ritchie. During the year telegrams concerning the discovery of nineteen asteroids and seven comets, and others relating to two orbits and to four positions of comets have been sent out, requiring in all 624 telegrams and 12 cable messages.

Publications. — The zone catalogue of stars between the declinations $+55^\circ\ 10'$ and $+49^\circ\ 50'$ has been printed, and the introduction has been sent to the printer, as stated above in describing the work done under the direction of Professor Rogers. This catalogue, with its introduction, will form Volume XV., Part II., of the Annals of the Observatory. Volume XIX., Part II., will be completed by the publication of a discussion of atmospheric refraction, the materials for which are derived from photographic observations. This work has been in progress during the year, but is not yet fully ready for printing. Volume XXI., Part II., mentioned last year as about to be published, has been printed and distributed. It contains the observations of the New England Meteorological Society for 1889, with essays by officers of the Society on climate and sea breezes. Volume XXIII., Part I., containing a description of the observations with

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the meridian photometer in the years 1882 to 1888, inclusive, has also been printed and distributed. Volume XXIV., containing the catalogue of 20,982 stars derived from these observations, which was printed last year, has since been distributed. Volume XXV. is not yet undertaken. Volume XXVI., Part I., which contains a description and discussion of the observations made with the Bache photographic telescope during the years 1885 to 1889, has been completed; and Volume XXVII., printed last year, has likewise been distributed. It forms part of the Henry Draper Memorial, and contains a catalogue of the spectra of 10,347 stars, to be known as the Draper Catalogue. Volume XXX., Part I., also printed last year, has been distributed, as has Part II., of the same volume, more recently printed. The whole volume forms a continuation of Volume XX., and contains meteorological observations made at the Blue Hill Observatory during the years 1889 and 1890, with a summary of observations for the five years ending with 1890. Volume XXXI., Part I., will soon appear, 130 pages being already in type. It forms the continuation of the observations of the New England Meterological Society, the publication of which was begun in Volume XXI.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-fifth Annual Report of the Astronomical Observatory of Harvard College. Cambridge, 1890.

Variable Stars of Long Period. Cambridge, 1891.

History and Progress of the Henry Draper Memorial. Extracted from the Annals of the Observatory, Volume XXVI., Part I.

Harvard College Observatory. A circular inviting subscriptions for the new fire-proof building.

A Possible Secondary Cause of the Phenomenon of Gegenschein. By Arthur Searle. Astronomische Nachrichten, cxxvi. 115.

Observations of Comets 1889 I., 1889 V., companion to 1889 V., Comet 1890 II., 1890 III., 1890 VI. By O. C. Wendell. Astronomische Nachrichten, cxxvi. 43.

Observations of Comet 1890 IV. By O. C. Wendell. Astronomische Nachrichten, cxxvi. 121; also, Astronomical Journal, x. 102.

Second series of Observations of Comet 1890 IV. By O. C. Wendell. Astronomische Nachrichten. cxxvii. 297; also, Astronomical Journal, x. 123.

Observations of Comet 1882 II. By O. C. Wendell. Astronomische Nachrichten, cxxvii. 293.

Observations of Comet 1889 I., Comet 1890 II., Comet 1890 III., Comet 1890 VI., and Comet a 1891. By O. C. Wendell. Astronomische Nachrichten, cxxvii. 297; also, Astronomical Journal, xi. 4.

Ephemeris of Comet 1890 VI., for November, 1890. By O. C. Wendell. Sidereal Messenger, ix. 419.

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Ephemeris of Comet 1890 II., for December, 1890. By O. C. Wendell. Sidereal Messenger, ix. 465.

Orbit and Ephemeris of Comet 1890 IV. By O. C. Wendell. Sidereal Messenger, x. 35.

Ephemeris of Comet 1890 IV., for February, 1891. By O. C. Wendell. Sidereal Messenger, x. 102.

Ephemeris of Comet 1890 II., for March, 1891. By O. C. Wendell. Sidereal Messenger, x. 147.

Ephemeris of Comet 1890 II., for April, 1891. By O. C. Wendell. Sidereal Messenger, x. 201.

Orbit and Ephemeris of Comet a 1891. By O. C. Wendell. Sidereal Messenger, x. 288.

Ephemeris of Comet a 1891, for July, 1891. By O. C. Wendell. Sidereal Messenger, x. 368.

Stars having Peculiar Spectra, including New Variable Stars in Triangulum and Hydra. By M. Fleming. Astronomische Nachrichten, cxxvi. 117.

Stars having Peculiar Spectra. By M. Fleming. Ibid. cxxvi. 165.

Stars having Peculiar Spectra. New Variable Stars in Perseus, Triangulum and Hydra. By M. Fleming. Sidereal Messenger, x. 7.

Astronomical Expedition to Peru. By M. Fleming. Ibid. x. 105.

Stars having Peculiar Spectra. New Variables in Aquarius and Delphinus. By M. Fleming. Ibid. x. 106.

New Variable Star in Camelopardalis. By M. Fleming. Ibid. x. 152.

The New Red Star in Auriga. By M. Fleming. English Mechanic, liii. 50.

Objects of Interest on Spectrum Plates and Two New Variable Stars in Perseus. By M. Fleming. Astronomische Nachrichten, cxxvi. 163.

Stars having Peculiar Spectra. New Variable Stars in Aquarius, Delphinus, and Camelopardalis. By M. Fleming. Ibid. cxxvii. 5.

New Planetary Nebula. DM. -12° 1172. By M. Fleming. Sidereal Messenger, x. 240.

Stars having Peculiar Spectra. New Variable Star in Sagittarius, R. A. $19^{h}\ 51.8^{m}$ Dec. $-42^{\circ}\ 7'$. By M. Fleming. Astronomische Nachrichten, cxxviii. 11.

Stars having Peculiar Spectra. New Variable Star in Lacerta. DM. $+39^{\circ}$ 4851. By M. Fleming. Ibid. cxxviii. 121.

Aid to Astronomical Research. By Edward C. Pickering. Reprinted in Sidereal Messenger, ix. 473.

Close Binary Stars. By Edward C. Pickering. Sidereal Messenger, x. 5.

A Fifth Type of Stellar Spectra. By Edward C. Pickering. Astronomische Nachrichten, cxxvii. 1.

The Discovery of Double Stars by Means of their Spectra. By Edward C. Pickering. Astronomische Nachrichten, cxxvii. 155.

Spectrum of β Lyrae. By Edward C. Pickering. Astronomische Nachrichten, cxxviii, 39. Reprinted in The Observatory, xiv. 341.

The Draper Catalogue. By Edward C. Pickering. Nature, xliv. 223.

EDWARD C. PICKERING, *Director*.

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Reprint from ASTRONOMY AND ASTRO-PHYSICS, No. 105.

STARS HAVING PECULIAR SPECTRA.

M. FLEMING.

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STARS HAVING PECULIAR SPECTRA.*

M. FLEMING.

A recent examination of photographs of stellar spectra taken with the 8-inch Draper telescope, at Cambridge, and with the Bache telescope under the direction of Professor Wm. H. Pickering, at the station near Arequipa, Peru, adds to our list of objects of interest the stars given in the following table. The successive columns contain the designation of the star, the approximate right ascension and declination for 1900, the magnitude, and a brief description of its spectrum. The date and station at which the photograph was taken are given in the last two columns.

Design.	R A.	Decl.	Mag	Description.	Date.	Station.
	1900 h m	1900 °				
DM. + 53° 379	1 38.7	+ 53 28	9 4	IV Type	Dec. 30, 1891	Cambridge
DM. + 38° 2389	12 54.7	+ 38 20	8.6	IV Type	Mch. 28, 189	Cambridge
Z. C. XV*h* 4129	16 0 6	— 25 57	8½	V Type	Aug. 5, 1891	Arequipa.
A. G. C. 24550	17 57.7	— 24 22	6.1	F line bright	Aug. 2, 1891	Arequipa.
DM. — 11° 4593	18 13.5	— 11 40	8 7	V Type	July 14, 1891	Arequipa.
DM. + 61° 2233	21 57.6	+ 62 0	7.0	F line bright	Feb. 18, 1892	Cambridge.

The spectra of the third and fifth stars in the above list are of the same class as those given in the list published in the *Astronomische Nachrichten*, Bd. 127, p. 3, and they increase the number of these objects to 40. The galactic longitudes of these two stars are 290° 39′ and 347° 36′ respectively; their galactic latitudes are + 17° 39′ and + 0° 35′. The spectrum of the fourth star shows other bright lines besides F.

An interesting change has taken place in the spectrum of 11 Monocerotis (H.P. 1220), magn. 4.2, whose approximate position for 1900 is in R. A. 6^h 24.0^m, decl. —6° 58′. A bright line near F changes its position with regard to that line in a manner similar to the bright lines in β Lyræ. Photographs taken with the 11-inch Draper telescope on Dec. 14, 1888, Dec. 23, 1889, and Jan. 22, 1890, show this line as having a shorter wave-length than F, while those taken on Feb. 16, 1892, and Feb. 18, 1892, show it as having a greater wave-length. A detailed study of this object will be made.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., April 14, 1892.

*Communicated by Edward C. Pickering, Director Harvard College Observatory.

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Reprint from ASTRONOMY AND Astro-PHYSICS, No. 103.

THE OBJECTIVE PRISM.

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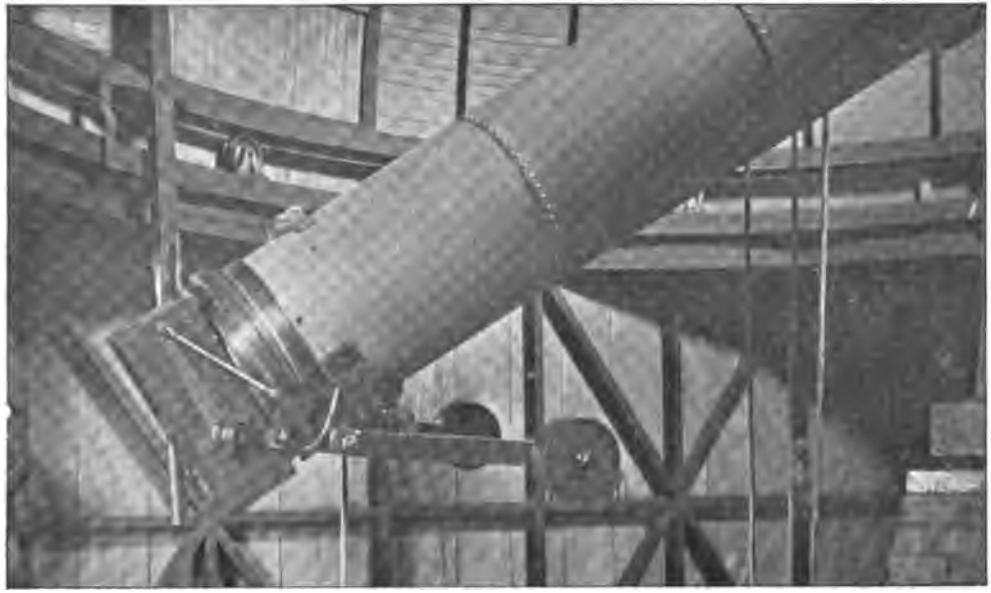

Objective Prism at the Harvard College Observatory.

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THE OBJECTIVE PRISM.*

Two methods have been used for photographing the spectra of the stars. The first of these methods, placing a large prism over the objective of a telescope, was that employed by Fraunhofer in observing stellar spectra visually. It was also used by Secchi for the same purpose. The second method consists in receiving on the slit of a spectroscope the image of a star formed at the focus of a telescope. This method was used by Dr. Draper and Dr. Huggins, and is that now employed at the Potsdam Observatory. The first of these methods has been used at the Harvard College Observatory during the last seven years. It possesses the advantages that the loss of light is very small, the spectra of all stars contained in the field of the instrument are photographed and slight errors in the clock driving the telescope are unimportant. In fact the clock is made to run a little faster or slower than sidereal time, since otherwise the image of each star would be spread into a narrow line in which the spectral lines could not readily be distinguished. By the change in rate this line moves over the plate at right angles to its length, forming a band whose width depends on the rate of the clock and the duration of the exposure. If the deviation from sidereal time is small, the image moves slowly over the plate, and a photograph will be obtained even if the star is very faint. In this case a long exposure should be used, otherwise the band will be too narrow. A variation in the rate of the clock, or other change affecting the right ascension, will only alter the density and breadth of the spectra. A variation in the differential refraction or other change affecting the declination will alter the direction of the spectral lines, rendering them oblique or curved instead of perpendicular to the direction of the spectrum. This will not affect the intensity of the image. With a slit spectroscope, the image of the star must be kept exactly on the slit, the least deviation causing all the light to be lost. It has, however, the great advantage that a comparison spectrum may be photographed by the side of the stellar spectrum, and the true wave-lengths thus determined directly. This advantage is, however, apparent rather than real, since the hydrogen and other solar lines are present in nearly all the stars, and the wave-lengths of any additional lines may be determined differentially from them. When, however, we wish to obtain the absolute wave-lengths of these lines in order to measure the approach or recession of the stars, the slit spectroscope has hitherto alone been used. This seems to be the only portion of this work

* Communicated by Professor Edward C. Pickering.

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for which the objective prism cannot be employed. Experiments are still in progress (see H. C. O. Annals, Vol. XXVI, Part I, page xx,) by which it is hoped this difficulty may be overcome. The success of these experiments would permit a fixed reference line to be photographed upon the spectrum always having the same position with regard to it. The precision with which measures of the spectral lines can be made is sufficient to determine the approach or recession with great accuracy, if only the reference line can be measured equally well. If this can be done the slit spectroscope will possess but few advantages over the objective prism. By the latter method equally good definition may be obtained, since, as the loss of light is smaller, greater dispersion may be used. With the brightest stars, however, it is difficult to obtain a dispersion sufficient to utilize the full advantages of this method. With a large telescope the prism would, of course, be heavy, expensive, and from its thickness, would cause considerable loss of light. The objective prism has special advantages in studying the spectra of the fainter stars, since all in the field of the telescope may be photographed simultaneously. If a photographic doublet is used for an objective all stars of sufficient brightness in a region ten degrees square may be photographed at once. In some cases several hundred spectra appear upon a single 8×10 plate.

With means furnished by Mrs. Draper the spectra of the stars have been photographed at the Harvard College Observatory as a memorial to her husband, the late Dr. Henry Draper. For the brighter stars a telescope having an aperture of eleven inches, and corrected for the photographic rays, has been employed. Four large prisms were placed over the objective and gave spectra about six inches in length. By staining the plate with erythrosin, the sodium line, D was photographed in the brighter stars, both components being readily shown.

For the fainter stars one or two prisms only were employed. When the prisms were first attached to the end of the telescope, as their entire weight was about one hundred pounds, heavy weights were fastened to the other end of the tube of the telescope, and also to the end of the declination axis. It was, consequently, a laborious and perhaps dangerous operation to remove and replace the prisms. Therefore spectra and chart photographs could not readily be taken on the same night. A great improvement on this process was to remount the prisms in square boxes, which could be slid, like the drawers in a bureau, into a large box permanently attached to the cell of the objective. A series of cast iron rings could be bolted to the tube of the tele-

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scope, the weight of each ring being such that it would compensate for the weight of the corresponding prism. As each prism was removed a ring was attached, and it thus became unnecessary to change the counterpoise at the further end of the telescope and declination axis. It was still difficult for one person to make the change and much time was lost if frequent changes were required. The method now employed of attaching the large prisms to the telescope is shown in the accompanying engraving (Plate VIII). Two of the prisms only are now used and they are mounted in a square brass box. This is attached to the end of the telescope by a form of link motion. A cast iron bar is fastened to a pivot on each side of the cell, the line connecting the pivots passing through the centre of gravity of the prisms and box. The bars are also free to turn around pivots attached near the end of the tube of the telescope. At the further end of each bar is placed a counterpoise exactly balancing the prism and box, so that the latter will remain in equilibrium in any position. Two links, one on each side of the square box, connect its end with pivots attached to the tube of the telescope. The dimensions are such that in one position the box containing the prisms lies flat against the end of the cell and in another against the side of the tube. The first of these positions is shown in the photograph. Accidental movements of the prism are prevented by small pins attached to the bars by chains. The prisms can thus be removed and replaced in a few seconds without disturbing the balance of the telescope. About 4,400 photographs have been obtained with this instrument since January, 1886. They include the spectra of all stars north of $-30°$ and sufficiently bright to be photographed in this way. Among other interesting results this has led to the discovery that ζ Ursæ Majoris, β Aurigæ, and probably β Lyræ are close binaries. An expedition has been sent to Peru and similar photographs of the southern stars are now being taken with a telescope having an aperture of thirteen inches.

In a second investigation the Bache telescope is used, which has a photographic doublet for an objective having an aperture of eight inches. The advantages of this form of instrument for photographing very faint celestial objects were first recognized by the writer in 1869, when preparing to observe the total eclipse of the Sun of that year in Mt. Pleasant, Iowa. As the usual methods were inadequate to photograph the faint exterior portions of the solar corona, a local photographer, Mr. Hoover, was requested to take a photograph with a large

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portrait lens. The result was very satisfactory (Journal Franklin Institute, Vol. LXII, p. 54) and apparently gave the best picture of the outer corona obtained up to that time. The advantages of the doublet are first the large angular aperture which permits very faint stars to be photographed, and secondly, the extent of the field by which the stars in a large part of the sky can be taken upon a single plate. Good definition is obtained over a region five degrees square, while over a region ten degrees square the definition is sufficiently good for many purposes, such as the classification of spectra, variability in light, etc.

A prism having a refracting angle of thirteen degrees was placed over the objective of the Bache telescope and the entire sky north of — 20° was photographed with this apparatus using exposures of about ten minutes. About twenty-seven thousand spectra of more than ten thousand stars were obtained and are published under the name of The Draper Catalogue (H. C. O. Annals, Vol. XXVI, Part 1, and Vol. XXVII). Similar photographs, with exposures of sixty minutes, cover nearly all the northern sky and serve to classify the spectra of the fainter stars. By using a prism of five degrees, of which the dispersion is less, the spectra of still fainter stars are photographed. This dispersion is sufficient to show any marked peculiarities. Since July, 1885, 3,300 plates were obtained with this instrument at Cambridge and in California. It was sent to Peru in the spring of 1889 where it is now in use, and over 3,200 photographs taken there have already been received. When this instrument was removed from Cambridge, the want of it was so great that Mrs. Draper had another instrument constructed to replace it. This is known as the 8-inch Draper telescope, and with it over 5,300 photographs have been taken since August, 1889.

It is expected that a still further advance will be made with the great photographic telescope, the gift of Miss C. W. Bruce. This instrument will be three times the size of the Bache telescope which it will resemble in form. Its aperture will be twenty-four inches and it should, therefore, photograph stars one or two magnitudes fainter than those obtained with the Bache telescope. It is hoped that with the Bruce telescope satisfactory photographs of the spectra of stars of the tenth and eleventh magnitude may be obtained. The four glass disks required for the lenses have been cast and are now ready for grinding. The prism, which has an aperture of twenty-four inches, is completed.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Jan. 23, 1892.

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Reprint from ASTRONOMY AND ASTRO-PHYSICS, No. 103.

THE NEW STAR IN AURIGA.

EDWARD C. PICKERING.

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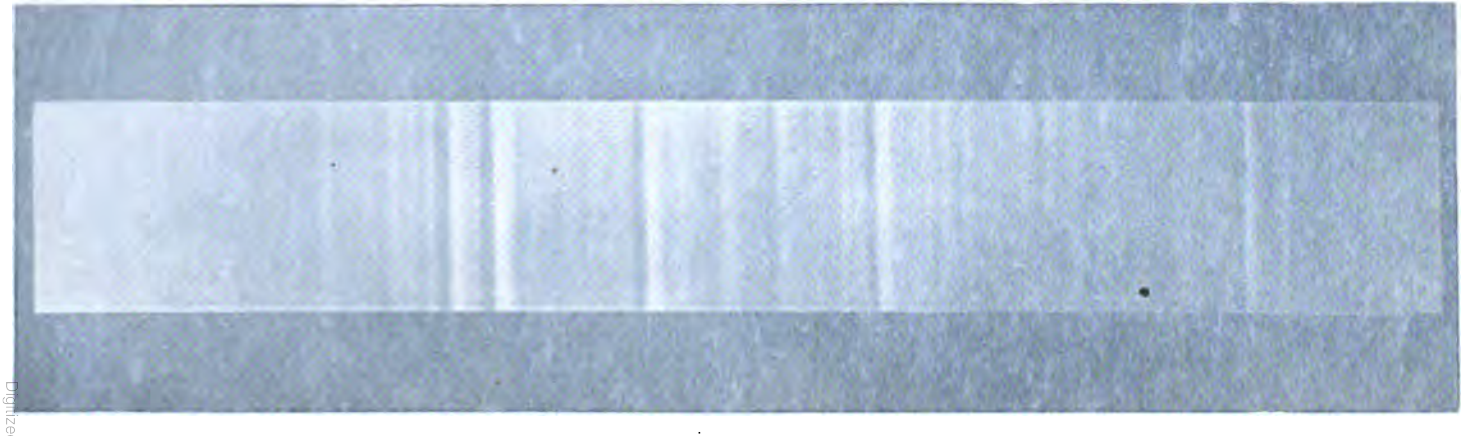

Nova Aurigæ. Photographed at Harvard College Observatory Feb. 5, 1892, with [illegible] Telescope. Exposure = 123 minutes.

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THE NEW STAR IN AURIGA.*

EDWARD C. PICKERING.

The photographs of the Henry Draper Memorial afford a means of studying the past condition of the portion of the sky in which the new star in Auriga has recently been discovered. Eighteen photographs of this region were taken with the 8-inch photographic telescopes from November 3, 1885 to November 2, 1891.

On none of them was the star visible, although on all but five, stars of the eleventh magnitude were shown, and on some of them stars of the thirteenth magnitude were visible. On the plate taken November 2 spectra of stars of the eleventh magnitude were shown. It is probable that the star was not visible during these six years. Five plates, on the other hand, taken from December 16, 1891, to January 31, 1892, show stars of the twelfth magnitude and the Nova appears as a bright star of the fifth magnitude. A still closer watch of the sky has been kept for the past year with an instrument intended to furnish the scale of stellar magnitudes of the brighter stars to which the stars photographed with the Bruce 24-inch photographic telescope will be referred. This instrument is called the transit photometer. It consists of a telescope having a Voightländer doublet of five inches aperture as an objective mounted like a transit instrument and driven automatically by clockwork in such a way that a region extending from 30° below the north pole to 30° in declination and in right ascension over three hours will be photographed on one plate.

The exposure given to each portion of this region is two seconds, and in this time stars of the sixth magnitude and brighter are distinctly shown. Plates were thus obtained on thirteen nights from October 21 to December 1, 1891. On none of these was the star visible, although χ Aurigæ, magnitude 5.00, was always clearly shown. On twelve nights beginning December 10, 1891, and ending on January 20, 1892, similar plates were obtained, on all of which the new star was clearly seen. Measurements of these images were made by Mrs. M. Fleming who also made the examination of the photographs described above. The Nova was compared directly with χ Aurigæ, and the difference in brightness estimated in grades as in Argelander's method of observing variable stars.

* Communicated by the author.

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To secure independence in the measurements an assistant recorded the numbers of the plates and the measures, rearranged their order according to chance, and returned them to Mrs. Fleming to be measured again. A third measure was made in the same way. On December 10, 11, 18, 28, and 30, 1891, and on January 5, 8, 9, and 16, two photographic images of the star were obtained. On December 17 and 18 the first measures were repeated. The corresponding dates, magnitudes and residuals expressed in tenths of a magnitude are given in the following table:

Date	Magn.	Residuals.
1891 December 10	5.37	0 −1 −1 0 0 0
" 11	5.83	0 0 0 +1 +1 0
" 13	5.22	0 0 0 +1 0 0
" 17	4.67	0 0 −1 −1 0 0
" 18	4.46	−1 −1 −1 +1 0 +1
" "		−2 −2 −2 −1 +1 +2
" 28	4.55	0 −1 −1 0 0 −1
" 30	4.60	−1 +1 0 −1 +1 0
1892 January 5	4.58	−1 0 +1 −1 −1 +1
" 8	4.72	0 0 0 +1 0 0
" 9	4.67	0 +1 −1 −1 0 −1
" 16	4.96	0 0 0 0 0 0
" 20	5.23	+1 0 0

The accordance of the measures is shown by the average residual which equals ± .05. From this it appears that the star was fainter than the eleventh magnitude on November 2, 1891, than the sixth magnitude on December 1, and that it was increasing rapidly on December 10. A graphical construction indicates that it had probably attained the seventh magnitude within a day or two of December 2, and the sixth magnitude December 7. The brightness increased rapidly until December 18, attaining its maximum about December 20 when its magnitude was 4.4. It then began to decrease slowly with slight fluctuations until January 20 when it was somewhat below the fifth magnitude. All of those changes took place before its discovery, so that it escaped observation nearly two months. During half of this time it was probably brighter than the fifth magnitude.

Since the announcement on February 2 of its discovery it has been closely followed at this Observatory both visually and photographically. Comparisons by Argelander's method visually are made every clear night by Mr. O. C. Wendell and Mr. W. M. Reed. Comparison stars have been selected so as to form a sequence having intervals of three or four tenths of a magnitude. Their numbers, positions for 1855.0 and magnitudes according to the Durchmusterung are given below when they occur in that catalogue. In other cases the positions have been determined

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directly. The first of these stars is 16 Aurigæ, the second χ Aurigæ. The faintest star *w* is of the twelfth magnitude.

Design.	D. M.	No.	R. A.	Dec.	Magn.
			h m s	° ′	
a	+ 33°	1000	5 8 39.8	+ 33 13.1	5.1
b	+ 32°	1024	5 23 18.4	+ 32 4.8	4.8
c	+ 33°	1013	5 10 28.7	+ 33 48.1	5.9
d	+ 29°	869	5 11 59.6	+ 29 25.4	6.0
e	+ 30°	898	5 17 51.4	+ 30 4.2	6.2
f	+ 29°	947	5 30 5.9	+ 29 7.6	6.2
g	+ 29°	909	5 20 27.9	+ 29 3.9	7.0
h	+ 27°	806	5 26 50.0	+ 27 33.7	7.1
k	+ 32°	1003	5 19 52.8	+ 32 4.8	7.4
l	+ 31°	1001	5 23 20.4	+ 31 55.0	7.6
m	+ 31°	989	5 20 56.5	+ 31 40.8	7.7
n	+ 30°	912	5 20 27.2	+ 30 28.4	8.5
o	+ 30°	913	5 20 48.6	+ 30 19.8	8.7
p	+ 30°	918	5 21 55.6	+ 30 3.9	9.3
q	+ 30°	914	5 20 48.8	+ 30 28.0	9.4
r			5 22 36.8	+ 30 27.5	
s			5 22 43.6	+ 30 21.2	
t			5 22 45.3	+ 30 26.2	
u			5 22 54.7	+ 30 18.3	
w			5 22 43.6	+ 30 29.4	
Nova			5 22 40.3	+ 30 19.9	

The magnitudes of all these stars will be determined photometrically for use in the final reduction. On every clear night Mr. Wendell also compares the Nova with the star *s* in the list given above. These observations are made with the 15-inch equatorial by means of a polarization photometer (H. C. O. Annals XI, Part I). Measures of the Nova and of the brighter comparison stars are made by Mr. S. I. Bailey and the writer with the meridian photometer. Five independent series of visual observations will thus be obtained which will test the reality of any apparent fluctuation. The position of the Nova with regard to Weisse 5^h 709 which is DM. + 30° 9 12, has been determined by Mr. Wendell with the 15 inch equatorial. The dates, the resulting differences in right ascension and declination, and the position for 1900.0 are given below.

Date 1892	$\Delta\alpha$ m s	$\Delta\delta$ ′ ″	α 1900.0 h m s	δ 1900.0 ° ′ ″
Feb. 4	− 1 48.20	− 6 21.2	5 25 33.40	+ 30 22 13.2
Feb. 6	− 1 48.29	− 6 19.9	5 25 33.31	+ 30 22 14.5
Feb. 9	− 1 48.33	− 6 20.3	5 25 33.27	+ 30 22 14.1
All	− 1 48.27	− 6 20.5	5 25 33.33	+ 30 22 13.9

Photographic charts are made every clear evening with the 8-inch Draper telescope, and photographs are also taken with the transit photometer.

An important series of photographs of the spectrum is being obtained with the 11-inch Draper telescope, and since the star

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will probably soon be too faint to photograph in this way, spectra are also taken with the 8-inch telescope using a small dispersion. The spectrum can thus be photographed until the star is as faint as the eleventh magnitude. With these last photographs several lines, including F, G, h, K, and α, appear to be bright. But on closer examination they are shown to be really dark with the edge of greater wave-length bright. This is confirmed with the greater dispersion, the bright lines really consisting of broad bands sharply defined on the edge of smaller wave-length. The breadth of the bands is not due to poor definition since numerous fine lines are also visible. Many of the lines, including the K line and those due to hydrogen are double. The evidence that this doubling is due to the different velocities of different portions of this object is not conclusive owing to the breadth of the bands. The difference in velocity indicated by the separation of the lines is about 370 kilometers per second. The apparent separation of the different lines in the photograph increases as the wave-length diminishes, as it should according to this theory owing to the increasing dispersion of the violet rays. Two explanations have been offered of the sudden increase in light of stars of this class—the mechanical theory that it is caused by approach or collision, and the chemical theory that it is due to volcanic action. The doubling of the lines strengthens the first of the above theories rather than the second.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., February 15, 1892.

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Reprint from ASTRONOMY AND ASTRO-PHYSICS, No. 105.

NOVA AURIGÆ.

EDWARD C. PICKERING.

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NOVA AURIGÆ.*

EDWARD C. PICKERING.

The new star in Auriga has now become very faint. It has been photographed at the Harvard College Observatory on about forty nights since December 10, 1891, and observed visually on about thirty nights since February 3, 1892. After undergoing slight fluctuations, it began to diminish in light during the latter part of February. It attained the magnitude 6.0 on the scale of the meridian photometer about March 4; 7.0, March 10; 8.0, March 13; 9.0, March 16; 10.0, March 20; 11.0, March 22; 12.0, March 25; 13.0, March 29; 14.0, April 6, and is now, April 13, of about the magnitude 14.3. After March 7 the cause of the outburst and fluctuations in light appeared to cease to act, and the star began to fade with such regularity that it promised to furnish a test of the correctness of Dulong and Petit's law of cooling. After three weeks, during which the light had diminished about six magnitudes, the change became less rapid and the light is now diminishing slowly. The remarkable increase of light of more than half a magnitude between February 16 and 17 was shown by various series of observations. The reality of several smaller changes can also be checked by the variety of methods employed.

The spectrum was last photographed on March 29, when the star had the magnitude 13, but the bright lines were not well shown after March 24, when the magnitude was 11.6. The principal bright lines faded in the order K, H, α, F, h and G, the latter line becoming much the brightest when the star was faint.

A complete discussion of these measures will be published shortly. Observers are invited to send to the undersigned any comparisons they may have made of the light of the Nova with other stars. Observations are particularly desired on those nights on which it was cloudy at Cambridge.

HARVARD COLLEGE OBSERVATORY, Cambridge, Mass.,
April 14, 1892.

* Communicated by the author.

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FORTY-SEVENTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING OCTOBER 31, 1892.

BY

EDWARD C. PICKERING.

CAMBRIDGE, MASS.
PUBLISHED BY THE UNIVERSITY.
1892.

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REPORT.

To the President of the University: —

Sir, — By the death of Mr. George B. Clark of the firm of Messrs. Alvan Clark & Sons, the Observatory has lost a friend of many years standing. To his genius for mechanical devices, indomitable perseverance, and devotion to the interests of the Observatory, we are indebted for the success of many of our most useful instruments.

The most important matters to be considered in the following report are, the permanent establishment of an observing station in South America, where the difficulties depending on the unsteadiness of the air are almost entirely avoided; the construction of a new brick building, by which the photographs and manuscripts of the Observatory will be securely protected from the danger of fire; the approaching completion of the Bruce photographic telescope, and the observation by a variety of methods of the new star in Auriga.

Observatory Instruments.

East Equatorial. — While the photometric observation of the eclipses of Jupiter's satellites, and various kinds of micrometric work, as described below, continue to be carried on with this instrument, its principal use in recent years, like that of the West Equatorial, has become the systematic observation of variable stars. The stars chiefly observed are seventeen circumpolar variables of long period, but about seventy others also receive attention. The objects contemplated are, the formation of lists of comparison stars, proceeding by intervals of about half a magnitude from the maximum of each variable to its minimum or to the faintest star visible, as the case may be: the determination of the magnitude of each comparison star, at least by means of comparisons between it and others, and when practicable, by photometric methods; and finally, the observation of the variable star itself at intervals of two weeks or less. The lists of comparison stars are usually first selected by means of the West Equatorial, and revised by means of the larger instrument. The variable stars themselves are observed with the West Equatorial until they become too faint to be seen in it, when further observations of them are made with the East Equatorial. It is much to be desired that some observer, having a still larger instrument at his dis-

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posal, should systematically observe the stars which become too faint for the East Equatorial, until they have recovered sufficient brightness to make them again visible here.

The observations with the East Equatorial were made by Mr. O. C. Wendell, except 11 of the 29 eclipses of Jupiter's satellites measured photometrically during the year, which were made by the Director. The total number of eclipses photometrically observed since 1877 is now 500. More than 1000 observations of variable stars were made in pursuance of the plan above described, and lists of comparison stars for 37 variables were selected or revised. The new star in Auriga was compared with others 250 times, and was observed photometrically on 40 nights, during which 1344 separate settings of the photometer were made. The place of the new star was micrometrically observed on 3 nights, and several of the stars used in comparisons with it were also occasionally observed both with the photometer and the micrometer. The wedge photometer was used in 18 series of observations, comprising 1422 settings, for determining the brightness of 474 stars, selected from the Durchmusterung. Comet 1891 V. was observed for position on 5 nights; Comet 1891 II. on 4; and the comets discovered by Swift, Denning, Brooks, and Barnard, were similarly observed on 11, 2, 2, and 1 nights respectively. A number of miscellaneous observations, mostly relating to the stars near variables, were also made.

Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision. During the year the catalogue of the zone between the declinations $+49°\,50'$ and $55°\,10'$ has been printed, and it is now ready for distribution. This work includes an elaborate introduction by Professor Rogers. The manuscript was sent to Germany for publication in accordance with an arrangement for coöperation between the Observatory and the Astronomische Gesellschaft, which also publishes an edition of this catalogue as a part of its general catalogue of stars to the ninth magnitude. The printing of another volume relating to the zone observations has made much progress, as mentioned below in describing the publications, and the journal of the observations has been carefully checked and in part recomputed during the year. It will occupy two additional volumes, which are expected to be ready for the printer in a few months.

The observations of the southern zone between the declinations $-9°\,50'$ and $-14°\,10'$ were so far completed during the spring by Professor Searle, with the assistance of Mr. Dunne, that the observations still to be made are only such as will be shown to be necessary

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by the progress of the reductions. Observations have therefore been suspended for the present. The number of nights of observation for the months of November, 1891, to May, 1892, inclusive, was 50; the total number of observations was 2132, of which 100 relate to circumpolar stars, 321 to fundamental stars, 1680 to zone stars, 29 to variable stars, and 2 to stars incidentally observed. The total number of observations made since the work began in April, 1888, is 25,922, and the corresponding numbers for the five classes of stars just mentioned are 961, 3329, 20,966, 128, and 538; the total number of nights of observation was 490. The work of reduction continues to make good progress. At present, it is directed chiefly to the completion of the reduction of the fundamental stars. An examination of their residuals for the first year has made evident a systematic variation dependent upon the declination of the stars, which it will be desirable to investigate for the whole series of observations.

Meridian Photometer. — Observations of the light of the southern stars with the meridian photometer were completed by Mr. Bailey on May 6, 1891. These measures give the brightness of about eight thousand stars south of $-30°$ and continue the work contained in Volumes XIV. and XXIV. of the Annals, to the South Pole. The reduction of these observations is now approaching completion. Much attention has been paid to the discussion of the atmospheric absorption as many of the polar stars were observed at a large zenith distance. On the return of the photometer to Cambridge, preparations were made to resume work with it here. It was accordingly mounted in the west wing of the main building, so that the observer and recorder should be in a warm room in winter, instead of being exposed to the cold. Observations began November 3, 1891, and since then 105 series have been obtained, including 33,792 separate photometric comparisons; 36 of these series, including 10,216 comparisons, have been made by Mr. Bailey, the remainder were made by the Director. The principal work undertaken has been the reobservation of the stars of the Harvard Photometry. It is now about ten years since the completion of the observations contained in that work. The list for observation also includes a number of stars which are slightly fainter than the sixth magnitude, and such of the comparison stars for variables employed in the observations made with the East Equatorial as are brighter than the tenth magnitude. Numerous observations are also made of stars near the northern and southern horizon, to determine the atmospheric absorption, the southern stars also serving to connect the scale of magnitude with that

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derived from the observations in Peru. A large part of the reduction and discussion of these observations has already been made. On 16 nights measures were made of the new star in Auriga, and of 25 stars suitable for comparison with it. The numbers of settings in these cases were 600 and 532 respectively.

West Equatorial. — The principal observer with this instrument has been Mr. W. M. Reed. Mr. T. E. Powe has also made many observations with it. Mr. Reed has observed on 109 nights. In pursuance of the system above described for the observation of variable stars of long period, he has selected 285 comparison stars, and has made 803 observations of the brightness of stars to be compared with variables of long period; 458 observations of such variables themselves, and 62 of variables of short period. He has also used the prismatic photometer mentioned in the last report, as yet chiefly in the observations required for determining its constant. The new star in Auriga has also been frequently observed; 116 observations, involving 277 comparisons, have been made by Mr. Reed, who has also made 118 observations of the corresponding comparison stars. Mr. Powe has made 50 observations of the new star, and 54 of the comparison stars; also 249 and 388 observations respectively of variable stars of long and of short period, and 57 observations of stars for comparison with variables of long period. Mr. Reed, aided by Mr. Powe, has observed a number of auroras, and has investigated the parallax of two auroras by combining his observations with others made at Blue Hill and at Providence.

Henry Draper Memorial.

The number of photographs taken with the 8 inch Draper telescope is 2777. The number taken in Peru with the Bache telescope is nearly two thousand, of which 601 have been received in Cambridge. The examination of these plates has as usual led to the discovery of a large number of interesting objects. Ten variable stars, U Delphini, S Pegasi, T Aquarii, R Crateris, R Carinae, S Canis Minoris, S Carinae, R Ophiuchi, X Ophiuchi and Espin's variable star in Auriga in addition to the thirty-seven previously announced have the hydrogen lines bright in their spectra. Seven new variable stars have been discovered this year by means of this property. The number of stars of the fifth type has been increased by eight, making the total number now known of these objects, 45. The hydrogen line F was shown to be bright in the spectra of six stars in addition to those already known. Photographs have been obtained of the spectra of

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eight planetary nebulae showing bright lines. The spectrum of the nebula surrounding 30 Doradus is unlike that of other gaseous nebulae. The star A. G. C. 20,937 has a somewhat similar spectrum. Five stars have been shown to have spectra of the fourth type. All of these peculiarities have been detected by Mrs. Fleming except in the cases of one of the known variables, one of the planetary nebulae, and two of the stars of the fourth type, which were found by Mr. A. E. Douglass, in Peru, before the plates were sent to Cambridge.

The amount of valuable material accumulated with these instruments is continually increasing, and has proved useful in many cases in studying the history of newly discovered objects. The brightness for several years past of stars suspected of variability has been furnished to various astronomers. Plates have been sent to the Lick and Amherst Observatories and to the Smithsonian Institution for special investigations. From one of them a new variable star in Aries was discovered by Professor Schaeberle. It is hoped that this use of our plates may increase in the future. A large number of photographs were taken of the new star in Auriga. An examination of the older photographs showed that the region containing it had been photographed eighteen times from November 3, 1885 to November 2, 1891, and that it was then apparently fainter than the thirteenth magnitude. It appeared upon five plates taken between December 16, 1891, and January 31, 1892. After its discovery it was photographed on sixty-five chart plates and thirty-six spectrum plates, until April 6, when it became too faint to be visible in the encroaching twilight. All of these plates have been carefully studied and measured. 21 charts and 15 spectrum plates of this object have been taken since its reappearance in September, 1892. On these last plates, the spectrum is shown to resemble that of a planetary nebula.

Many photographs of the lunar eclipse of November 15, 1891, were taken both at Cambridge and at the Boyden observing station near Arequipa, Peru. The examination of these photographs for the detection of a possible lunar satellite led only to a negative result.

The number of photographs taken with the 11 inch Draper telescope is 996. They include 372 spectra of β Aurigae to determine the law of periodic doubling of the lines. 244 of these images show the lines double so that the separation can be measured. In like manner 208 spectra of ζ Ursae Majoris have been photographed, and in 49 of them the lines are separated widely enough to be measured. A similar study has been made of the new star in Auriga, of β Lyrae,

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of 11 Monocerotis, and of some other stars having peculiar spectra. Photographic charts have also been obtained of numerous variable stars, stars having large proper motion, clusters and stars having peculiar spectra to determine their parallax if it is perceptible.

Boyden Department.

In establishing the Fund that bears his name, Mr. Boyden desired to secure an astronomical station where the effects due to the atmosphere would be greatly diminished. This has now been successfully accomplished in the Harvard Station at Arequipa, Peru, where the effect of the air is no longer as heretofore the principal obstacle to progress in astronomy. Instead of this the limit is now the size and excellence of our instruments. A great advance would probably be made in our knowledge of the planets, and perhaps of the fixed stars, if a telescope of the largest size could be mounted under such favorable conditions.

This station has continued in charge of Professor W. H. Pickering. The instruments chiefly employed have been the 13 inch telescope, the 8 inch Bache telescope, and a photographic camera having an aperture of 2½ inches. The first of these instruments has been largely devoted to visual work, for which unusual advantages are afforded by the transparency and steadiness of the air at this station. Many interesting results have been derived from the observations made of the Moon and various planets. The observations of the Moon relate to Plato and other regions, which have been carefully examined, and also to the systems of bright streaks visible at full Moon. The markings of Mercury have been studied, and this investigation appears to confirm Schiaparelli's view that the rotation of Mercury on its axis occupies the same time as its revolution in its orbit. Although this planet appears to have no atmosphere, the markings upon it are very faint compared with those upon the Moon. Venus was micrometrically studied near its inferior conjunction with regard to its diameter, polar compression, and the refractive effect of its atmosphere. No permanent markings could be detected. An extensive series of observations was made upon Mars. The relative positions of 92 points upon its surface were determined by the micrometer. More than 40 minute black points were discovered, provisionally designated as lakes. The polar compression of the planet was measured, and appeared to be greater than that indicated by theory, which may be due to an excess of cloud in the equatorial regions. The presence of the dark and narrow streaks called canals by Schiaparelli has been confirmed and various measurements of them have been made. The

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clouds projecting beyond the limb and terminator, discovered at the Lick Observatory, have been studied, and their height has been found to be at least twenty miles. The relative colors of different portions of the planet have been minutely observed. Two large dark blue areas have been detected, and other portions have been noticed to be subject to gradual changes of color.

Many new double stars were found in a survey of the heavens south of $-30°$, between 12^h and 18^h. The August occultation of Jupiter was observed both visually and photographically, as was also the new star in Auriga, and Swift's comet, the photographs of which showed detail not noticeable in the visual observations.

With the camera, having the aperature $2\frac{1}{2}$ inches, very satisfactory photographs have been obtained of the Magellanic clouds, showing their composition to be partly of stars and partly of nebulous matter; also the spiral structure of the larger of the two clouds.

Meteorological observations are regularly carried on. Stations have been established at Mollendo, 100 feet above sea level, at La Joya, the elevation of which is 4150 feet, at the observing station, 8060 feet high, at the Chachani Ravine, 16,650 feet high, where numerous miscellaneous observations have been made. Notwithstanding the great height of the last named station, it can be reached by a mule path, and a hut has been erected where the observers can pass the night. A survey of the Arequipa valley and neighboring mountains has been made, depending on two separate base lines. The heights of the mountains have been measured, and in some cases the result has been checked by a mercurial barometer.

The Bruce Photographic Telescope.

This instrument, which if successful will be in many respects the most powerful in the world, is now rapidly approaching completion. The eight surfaces of its objective have been ground and polished so that it could be tested on a star. The results were satisfactory, although of course no definite opinion can be formed until the final corrections are applied. The focal length proved to be that desired within half of one per cent. Plans have been made and the foundations laid for a one story brick building with a sliding roof in which it will be erected during its trial in Cambridge. After this, it is proposed to send it to the Arequipa station in Peru.

Photographs have been taken with the transit photometer on 192 evenings, and when clear, throughout the entire night. With this instrument images are obtained of all stars brighter than the sixth magnitude which cross the meridian during the night. The value

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of this work was illustrated when the new star in Auriga was discovered in February, 1892. It then appeared that this object had been photographed on twelve nights since December 10, 1891, while no trace of it was visible on thirteen plates covering this region and taken before December 2, 1891. The only knowledge that exists of its changes of light during the six weeks in which it remained undiscovered is furnished by these photographs and those taken with the 8 inch telescopes. It was also photographed with the transit photometer on twelve nights after its discovery. Of the forty thousand standard stars of the tenth magnitude, about eight thousand have been selected by Miss E. F. Leland during the past year, making eleven thousand in all.

Miscellaneous.

Library. — The library of the Observatory has been increased during the year by the addition of 169 volumes and 964 pamphlets. The total numbers of volumes and pamphlets on November 1, 1892, were 7198 and 8745, respectively.

As the station at Arequipa, Peru, will probably be maintained permanently, it is desirable that it should have a library of its own. Owing to its remoteness, copies of astronomical or meteorological works sent there direct, or through this Observatory, will be gratefully received and will prove of much value.

Time Service. — The action of the U. S. Naval Observatory in furnishing the public with time signals of moderate accuracy has not proved as injurious to this Observatory as to many others. It has rendered it advisable however to abandon the Harvard system of time signals. This was done with less reluctance since the continual increase in the number of electric wires rendered it every year more difficult to maintain continuous service. The danger of accident or fire from the powerful currents transmitted by other lines was insufficiently compensated by the pecuniary profit derived from the sale of our time signals. The principal benefit to the Observatory arose from the appreciation by the public of the service rendered in furnishing time signals of the highest attainable accuracy.

Telegraphic Announcements. — The distribution of telegraphic announcements of discovery has been continued as in past years, although Mr. Ritchie has resigned his position as Assistant in the Observatory. Astronomers are requested to continue to send to this Observatory announcements of their discoveries for transmission to the observatories of Europe and America.

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Buildings and Grounds. — The urgent need by the Observatory of a fire-proof building to hold its large collection of photographic plates, has been pointed out in several successive reports. This want has at last been supplied by the following liberal contributions of the friends of the Observatory: —

A friend (Boston)	$500	Lawrence, Samuel C.	$100
A friend (New York)	500	Lee, Henry	500
Ames, Oakes A.	100	Lowell, John	100
Beebe, E. Pierson	100	Mason, W. Powell	200
Bradlee, Miss Helen C.	100	Nash, Nathaniel C.	100
Bremer, John L.	200	Paine, Robert Treat	300
Brimmer, Martin	300	Parkman, George F.	500
Coolidge, J. Randolph	100	Peabody, F. H.	500
Curtis, Charles P.	100	Peabody, Oliver W.	100
Edmands, J. Rayner	200	Pickering, Edward C.	500
Endicott, William, Jr.	500	Salisbury, Stephen	100
Forbes, John M.	200	Shattuck, George O.	100
Gardner, Mrs. John L.	1000	Thayer Brothers	200
Gardner, John L.	500	Warren, Samuel D.	200
Hemenway, Augustus	100	Weld, William F.	100
Hemenway, Mrs. Mary	500	Wheelwright, J. W.	100
Hudson, John E.	100		
Hunnewell, H. H.	200		$9,200
Kimball, David P.	200		

About two thirds of the total amount required has thus been provided. Unless future subscriptions are received the remainder must be taken from the sum available for the current expenses of the Observatory. A brick building, thirty by sixty feet, and having two stories and a basement has been erected and is now nearly completed. It will furnish a permanent storehouse for the glass photographs and the more valuable manuscripts of the Observatory, and also room for their examination and discussion.

The inadequate accommodation afforded by the East Wing of the Observatory, which is used as a dwelling house by the Director, has long been recognized. An arrangement has been made during the past year by which the amount deducted from the salary of the Director on account of his occupancy of the house is hereafter to be applied to the expenses of the Observatory instead of to those of the University at large. An extension has been made, at the expense of the Director, by which the accommodation for visiting astronomers and the rooms for entertaining them will be greatly improved. A large amount of grading has been done in connection with these buildings, and the hollow formed by the old entrance from Concord Avenue has been filled.

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Publications. — Volume XV., Part II. of the Annals of the Observatory has been completed by the printing of the introduction. This work contains the zone catalogue of stars between the declinations + 49° 50′ and + 55° 10′, and concludes Volume XV. It will soon be distributed. Volume XIX., Part II., is in type as far as page 314. It contains a discussion of the zodiacal light by Professor Searle, and a determination of the atmospheric absorption by means of photography. Volume XXV. is in type as far as page 356. It contains a comparison of the places of stars in the zone + 49° 50′ to + 55° 10′ as determined by Professor Rogers, with the places of the same stars in previous catalogues, the results thus obtained for proper motion, and the separate results in right ascension and declination derived from the successive observations of the zone stars. Volumes XXIII., Part II., XXVI., Part II. and XXVIII., are not yet undertaken. Volume XXIX. will consist of comparatively brief, disconnected articles, like Volume XVIII. Three numbers of this volume are in type. They relate respectively to meteorological observations by Messrs. A. Lawrence Rotch and Winslow Upton at the time of the total solar eclipse of January 1, 1889, which they observed at Willows, California; to the determination of the longitude of Smith College, made in 1888, by Miss Mary E. Byrd and Professor Mary W. Whitney; and to photometric observations of asteroids, by Mr. Henry M. Parkhurst, in continuation of his previous article in Volume XVIII. upon the same subject. The fourth number of Volume XXIX. is also by Mr. Parkhurst, and relates to his observations of variable stars. Twenty pages of this article are in type, extending to page 111 of the entire volume. Volume XXX., Part III., containing meteorological observations of the Blue Hill Observatory, has been printed and will soon be distributed; Part IV. is required to complete the volume. Volume XXXI., Part I. has been printed and will soon be distributed; Part II. is ready for printing. This volume contains observations and essays by members of the New England Meteorological Society, during the years 1890 and 1891. Volume XL., Part I., has been printed and is soon to be distributed. It continues the publication of the work of the Blue Hill Meteorological Observatory from Volumes XX. and XXX., and contains observations made during the year 1891. The volumes bearing numbers between XXXI. and XL. have not yet been undertaken.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-sixth Annual Report of the Director of the Astronomical Observatory of Harvard College. Cambridge, 1891.

A Large Southern Telescope. Circular describing the advantages of establishing such an instrument at Arequipa, Peru.

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Astronomical Possibilities at considerable altitudes. By W. H. Pickering. Astronomische Nachrichten, cxxix. 97. Reprinted in the Observatory, xv. 283.

An investigation of the systems of Bright Streaks visible upon the Full Moon. By W. H. Pickering. Astronomische Nachrichten, cxxx. 225.

Are there at present Active Volcanoes upon the Moon? By W. H. Pickering. The Observatory, xv. 250.

The Mountain Station of the Harvard College Observatory. By W. H. Pickering. Astronomy and Astro-Physics, xi. 353.

The Boyden Station of the Harvard College Observatory. By W. H. Pickering. Astronomy and Astro-Physics, xi. 357.

Colors Exhibited by the Planet Mars. By W. H. Pickering. Astronomy and Astro-Physics, xi. 449.

The Earthquake for February 23, 1892. By W. H. Pickering. Astronomy and Astro-Physics, xi. 470.

Colors Exhibited by the Planet Mars. By W. H. Pickering. Astronomy and Astro-Physics, xi. 545.

The Planet Saturn and its Satellites. By W. H. Pickering. Astronomy and Astro-Physics, xi. 649.

Mars. By W. H. Pickering. Astronomy and Astro-Physics, xi. 668.

The Glacial Period and the Planet Mars. By W. H. Pickering. Knowledge, xv. 113.

Can a Planet absorb its Oceans without having its Surface Temperature lowered? By W. H. Pickering. Knowledge, xv. 193.

Observations of Comet 1891 V. By O. C. Wendell. Astronomical Journal, xi. 56.

Second series of Observations of Comet 1891 V. By O. C. Wendell. Astronomical Journal, xi. 61.

Orbit of Comet 1891 IV. By O. C. Wendell. Astronomy and Astro-Physics, xi. 87.

Ephemeris of Comet 1891 IV., for March. By O. C. Wendell. Astronomy and Astro-Physics, xi. 251.

Observations of Comet a 1892. By O. C. Wendell. Astronomical Journal, xi. 158.

Orbit of Comet a 1892. By O. C. Wendell. Astronomy and Astro-Physics, xi. 443.

Observations of Comets 1891 II. and 1891 V. By O. C. Wendell. Astronomische Nachrichten, cxxx. 45; also Astronomical Journal, xi. 191.

Observations of Comets a 1892 and c 1892. By O. C. Wendell. Astronomical Journal, xi. 191.

Second Orbit of Comet a 1892. By O. C. Wendell. Astronomy and Astro-Physics, xi. 536.

Ephemeris of Comet a 1892 for August. By O. C. Wendell. Astronomy and Astro-Physics, xi. 625.

Second series of Observations of Comet a 1892. Also Observations of Comet c 1892. By O. C. Wendell. Astronomical Journal, xii. 94.

New Variable Stars in the Southern Sky. By M. Fleming. Astronomische Nachrichten, cxxx. 125.

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Stars having Peculiar Spectra. By M. Fleming. Astronomy and Astro-Physics, xi. 418.

Astronomical Expedition to Peru. By M. Fleming. Publications of the Astronomical Society of the Pacific, No. 22, 58.

Distribution of Energy in Stellar Spectra. By Edward C. Pickering. Astronomische Nachrichten, cxxviii. 377. Reprinted in Astronomy and Astro-Physics xi. 22.

On the New Star in Auriga. By Edward C. Pickering. Astronomische Nachrichten, cxxix. 111.

A New Variable Star in Aries. By Edward C. Pickering. Astronomische Nachrichten, cxxxi. 62.

The Objective Prism. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 199.

The New Star in Auriga. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 228.

A change in the Spectrum of Nova Aurigae. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 330.

Nova Aurigae. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 417.

Nova Aurigae. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 750.

A New Variable Star. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 752.

EDWARD C. PICKERING, *Director*.

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PUBLICATIONS

AND

PHOTOGRAPHIC ILLUSTRATIONS

ISSUED BY THE

ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE.

EDWARD C. PICKERING, DIRECTOR.

FIRST EDITION.

CAMBRIDGE:
JOHN WILSON AND SON,
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1893.

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PUBLICATIONS AND PHOTOGRAPHIC ILLUSTRATIONS ISSUED BY THE ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE.

THE work of the Astronomical Observatory of Harvard College is made known to the public in four ways: 1. By a series of Annals in quarto form now filling nearly thirty volumes. 2. By pamphlets and circulars, some of which have the quarto, others the octavo form. They include the annual reports of the Director, four annual reports on the Henry Draper Memorial, announcements of gifts to the Observatory, etc. 3. By silver prints of photographs of the size 8 by 10 inches, on card-board mounts. 4. By lantern slides. The silver prints and lantern slides in many cases represent the same objects, the scale of the lantern slides being one third that of the prints.

A large edition (six hundred to a thousand copies) is published of each volume of the Annals. These volumes are distributed gratuitously to the principal astronomical observatories, scientific societies, libraries, and to a few leading astronomers, specialists, and friends of the Observatory. The difficulty of making a suitable distribution is continually increasing with the establishment of new institutions. A similar distribution is made of the pamphlets and circulars, while, in the case of silver prints and lantern slides, the distribution has been small owing to the expense.

It is hoped that the work of the Observatory may be brought before a larger number of persons by the plan described below. The distribution of the Annals and other publications will be continued as heretofore, and special efforts will be made to complete imperfect sets in observatories and public libraries. Copies can in general only be given to individuals when at work upon the special subjects to which they relate. To all other institutions and individuals, the Annals will be sold at the prices given below. These prices are not remunerative, and it is the policy of the Observatory to supply the demand for the results of its work from persons especially interested in it, but not to attempt any large sale of its publications.

Few copies remain of several early volumes, or parts of volumes, belonging to the series of Annals. These can no longer be sold, and are specified as out of print in the list given below.

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The system of numbering the later volumes, which has been adopted, has for its object the suggestion of the relations existing between them in regard to the kind of observations which they contain. Thus, Vols. XIV. and XXIV. contain observations with the Meridian Photometer; Vols. XV. and XXV. relate to the zone of stars between the parallels of declination +49° 50′ and +55° 10′, observed with the Meridian Circle; Vols. XX., XXX., and XL. contain meteorological observations made at the Blue Hill Observatory; Vols. XXI. and XXXI. contain similar observations furnished by the New England Meteorological Society. This system will account for the fact, shown by the list given below, that many unpublished volumes will bear earlier numbers than those assigned to others which have already appeared.

Applications for any of the contents of the following lists should be addressed to the Publication Agent of Harvard University, Cambridge, Mass., U. S. A.

Annals of the Astronomical Observatory of Harvard College.

These Annals are of quarto size, and are usually bound in paper. The price is $5.00 for an entire volume, and $3.00 for a separate part of a volume, except in the cases specially mentioned in the list given below.

Vol. I., Part I. History and Description of the Observatory, 1840–1855, pp. cxci. Part II. Zone Catalogue of 5500 stars, situated between the Equator and 0° 20′ north declination, pp. xcvii. and 317. The places of these stars were determined by transit observations on a mica scale in the field of the large equatorial telescope. Additional observations of the same kind appear in Vol. II., Part II., and in Vol. VI. Part I. will be sold for $5.00; Part II. is out of print.

Vol. II., Part I. Observations on the Planet Saturn, pp. 136, and 31 plates. Part II. Zone Catalogue of 4484 stars, situated between 0° 20′ and 0° 40′ north declination, pp. 257. In continuation of Vol. I., Part II. Both parts of Vol. II. are out of print.

Vol. III. Account of the Great Comet of 1858, pp. xx. and 372, and 51 plates. Out of print.

Vol. IV., Part I. A Catalogue of Standard Polar and Clock Stars for the Reduction of Observations in Right Ascension, pp. 32. Part

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II. Right Ascensions of 505 stars determined with the East Transit Circle, 1862–1865, pp. xix. and 143. Part I. is out of print; Part II. will be sold for $5.00.

Vol. V. Observations on the Great Nebula of Orion, pp. xxvi. and 189, and 3 plates. The work includes a catalogue of 1101 stars near ι, θ, and c Orionis. Out of print.

Vol. VI. Zone Catalogue of 6100 stars, situated between 0° 40′ and 1° 0′ north declination, pp. 303. In continuation of Vol. I., Part II., and Vol. II., Part II.

Vol. VII. Observations of Solar Spots, 1847–1849, pp. 22. With 112 wood-cuts and lithographs, and a portrait of Prof. W. C. Bond.

Vol. VIII., Part I. Historical Account of the Observatory, 1855–1876, pp. viii. and 65, and 16 plates. Part II. Astronomical Engravings. These engravings, 35 in number, with 15 pages of explanatory text, illustrate various celestial phenomena. Both parts of Vol. VIII. are out of print, but some of the engravings may still be obtained separately, the price of each being 50 cents. The subjects of the engravings are given below. Those engravings, which can no longer be supplied, are specified as out of print. Plate 1, four views of Jupiter. Plate 2, four views of Jupiter (out of print). Plate 3, view of the Sun, compiled from several dates. Plate 4, three views of Lunar Craters (out of print). Plate 5, six successive views of a Solar Spot (out of print). Plate 6, four views of the Sun, from photographs. Plate 7, two views of the Sun, from photographs. Plate 8, Solar Prominences. Plate 9, Solar Prominences. Plate 10, Solar Prominences. Plate 11, drawings of Spectroscopes. Plate 12, Total Solar Eclipse, 1869. Plate 13, Total Solar Eclipse, 1870. Plate 14, Solar Spots. Plate 15, four views of Lunar Craters. Plate 16, view of Saturn. Plate 17, four views of the Sun. Plate 18, four views of Lunar Craters. Plate 19, views of Spectroscopes (out of print). Plate 20, four views of Lunar Craters (out of print). Plate 21, chart of the Moon. Plate 22, four views of Mars. Plate 23, Solar Prominences. Plate 24, central part of the Nebula in Orion. Plate 25, Clusters in Hercules. Plate 26, Comet of Donati, 1858. Plate 27, Nebula in Orion. Plate 28, Head of Comet of Donati, 1858. Plate 29, two views of Head of Comet of Donati, 1858. Plate 30, two views of Coggia's Comet, 1874. Plate 31, Coggia's Comet, 1874. Plate

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32, Trifid Nebula. Plate 33, Nebula in Andromeda. Plate 34, Ring Nebula in Lyra. Plate 35, Dumb-bell Nebula.

Vol. IX. Photometric Researches, by C. S. Peirce, 1872–1875, pp. vi. and 181, and 3 plates. Including a photometric catalogue of 494 stars. The instrument used in the observations was a Zöllner photometer.

Vol. X. Observations made with the Meridian Circle, 1871–1872, pp. xxxix. and 239, and 6 plates. With two catalogues, one of 289, the other of 275 stars. A third catalogue contains the right ascensions of various stars observed with the East Transit Circle in 1867 and 1868.

Vol. XI. Parts I. and II. Photometric Observations made principally with the equatorial telescope, 1877–1879, pp. 318.

Vol. XII. Observations made with the Meridian Circle, 1874–1875, pp. xcii. and 271. With two catalogues, one of 334, the other of 284 stars.

Vol. XIII., Part I. Micrometric measurements made with the equatorial telescope, 1866–1881, pp. v. and 204. Part II. Zone Observations made with the transit wedge photometer, 1882–1886, pp. 155.

Vol. XIV., Parts I. and II. Observations with the Meridian Photometer, 1879–1882, pp. viii. and 512. With a catalogue of the magnitudes of 4260 stars. A separate edition of this catalogue, with the omission of some details, under the name of the Harvard Photometry, is sold for $1.00.

Vol. XV., Part I. Catalogue of 1213 stars observed with the Meridian Circle, 1870–1879, pp. viii. and 145. Part II. Catalogue of 8627 stars between 49° 50′ and 55° 10′ north declination observed with the Meridian Circle, 1870–1884, pp. (39) and 176.

Vol. XVI. Observations of Fundamental Stars made with the Meridian Circle, 1870–1886, pp. cxli. and 337.

Vol. XVII. The Almucantar, an investigation made in 1884–1885, by S. C. Chandler, Jr. pp. ix. and 222, and 2 plates.

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Vol. XVIII. Miscellaneous Researches. I. Magnitudes of stars employed in various Nautical Almanacs, pp. 13. II. Discussion of the Uranometria Oxoniensis, pp. 14. III. Photometric Observations of Asteroids, by Henry M. Parkhurst, pp. 44. IV. Total Eclipse of the Moon, January 28, 1888, pp. 10, and 1 plate. V. Total Eclipse of the Sun, August 29, 1886. By William H. Pickering, pp. 27, and 4 plates. VI. Detection of New Nebulæ by Photography, pp. 5. VII. A Photographic Determination of the Brightness of the Stars, pp. 96. VIII. Index to Observations of Variable Stars, pp. 43. IX. Meridian-Circle Observations of Close Polar Stars, pp. 26. X. Meridian-Circle Observations of Stars near the South Pole, pp. 18. Appendix, pp. 5. Either of the ten numbers composing this volume will be sold separately for 50 cents. The volume is paged continuously; in all, pp. 308.

Vol. XIX., Part I. Meteorological Observations, 1840–1888, pp. 157. Part II. Observations of Zodiacal Light and of Atmospheric Absorption, 1840–1890, pp. 174.

Vol. XX., Part I. Observations made at the Blue Hill Meteorological Observatory, 1887, pp. xxi. and 141, and 7 plates. Part II. Observations made at the Blue Hill Meteorological Observatory, 1888, pp. 126.

Vol. XXI., Part I. Observations of the New England Meteorological Society, 1888, pp. 105, and 3 plates. Part II. Investigations of the New England Meteorological Society, 1889, pp. 168, and 11 plates.

Vol. XXII. Meteorological Observations made on the summit of Pike's Peak, 1874–1888, pp. xiv. and 475.

Vol. XXIII., Part I. Discussion of Observations made with the Meridian Photometer, 1882–1888, pp. 136, and frontispiece. Part II. Not yet published.

Vol. XXIV. Results of Observations with the Meridian Photometer, 1882–1888, pp. 267.

Vol. XXV. Comparison of observations of stars observed between 49° 50′ and 55° 10′ north declination with earlier observations and with each other.

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Vol. XXVI., Part I. Preparation and Discussion of the Draper Catalogue, pp. xxiv. and 192. Part II. Not yet published. Catalogue and Discussion of Stellar Photographs taken with the 8-inch Draper Telescope.

Vol. XXVII. The Draper Catalogue of Stellar Spectra photographed with the 8-inch Bache Telescope, pp. iv. and 388, and frontispiece.

Vol. XXVIII. Miscellaneous Researches. Henry Draper Memorial. Not yet published.

Vol. XXIX. Miscellaneous Researches. I. Meteorological Observations during the total solar eclipse of January 1, 1889, by W. Upton and A. Lawrence Rotch, pp. 34, and 2 plates II. Longitude of Smith College Observatory, by Mary E. Byrd and Mary W. Whitney, pp. 30. III. Photometric Observations of Asteroids, by Henry M. Parkhurst, pp. 24. IV. Observations of Variable Stars, by Henry M. Parkhurst. V. Magnitudes of bright stars north of +70° declination. Either of these five articles will be sold separately for $1.00. The paging is continuous. Other parts not yet published.

Vol. XXX., Part I. Observations made at the Blue Hill Meteorological Observatory, 1889, pp. xiii. and 75, and frontispiece. Part II. Observations made at the Blue Hill Meteorological Observatory, 1890, pp. 126. Part III. Measurements of Cloud Heights and Velocities, pp. 67, and frontispiece. Part IV. Not yet published. Each part will be sold separately at $1.50.

Vol. XXXI., Part I. Investigations of the New England Meteorological Society for the year 1890, pp. 156, and 5 plates. Part II. Investigations of the New England Meteorological Society for the year 1891. Not yet published.

Vol. XL., Part I. Observations made at the Blue Hill Meteorological Observatory in the year 1891, pp. xi. and 62.

It is expected that a subsequent edition of this circular will contain lists of photographs and lantern slides, with the prices at which they can be furnished.

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THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

The Astronomical Observatory of Harvard College may be regarded as first established by the appointment of the late William Cranch Bond as Astronomical Observer. He entered upon his duties at the beginning of 1840. The public interest in astronomy excited by the appearance of the comet of 1843 enabled funds to be obtained by subscription for the purchase of a large telescope, which, when mounted in 1847, had no superior, and but one equal, in the world. The resources of the Observatory have since that time been increased by various subscriptions, gifts, and bequests, of which those resulting from the wills of Edward B. Phillips and Robert Treat Paine provide for a large part of the general expenses of the institution. The Henry Draper Memorial, established by Mrs. Henry Draper of New York, for the continuation of the researches interrupted by the death of her distinguished husband, furnishes the means of studying the spectra and other physical properties of the stars. A fund was left by the late Uriah A. Boyden to establish an observing station at an altitude where the atmospheric conditions would be favorable to astronomical investigation, and this fund was transferred by its trustees to the Observatory. After numerous trials of different locations in Colorado, California, Chile, and Peru, the proposed station has been established near Arequipa, Peru, at an altitude of 8050 feet. By thus maintaining a station south of the equator, work at Cambridge may be extended to the southern stars. All important researches undertaken here are therefore now made to include stars in all parts of the sky, from the north to the south pole.

Still more recently Miss C. W. Bruce of New York has provided the means for a photographic telescope, having an aperture of 24 inches, which will be mounted first in Cambridge and later in Peru.

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In meteorological work the Observatory is associated with the Blue Hill Meteorological Observatory, the New England Meteorological Society, and the New England Weather Bureau, and provides for the publication in its Annals of the results obtained by the observers of these associated institutions.

PERMANENT STATIONS.

Desig.	Station.	Elevation in Feet.	Principal Instruments.
1	Harvard College Observatory, Cambridge, Mass.	'74	A, B, C, E, F, G, H, J, K, M, N.
2	Blue Hill Meteorological Observatory, Readville, Mass.	640	Meteorological.
3	Base Station of Blue Hill Observatory, Readville, Mass.	200	Meteorological.
4	Valley Station of Blue Hill Observatory, Readville, Mass.	40	Meteorological.
5	Arequipa Station, Peru.	8,050	D, I, L.
6	Ravine Station, Mt. Chachani, near Arequipa, Peru.	16,650	Meteorological.

TEMPORARY STATIONS.

Desig.	Station.	Nature of Observations.	Years.	Elevation in Feet.	Principal Inst.
7	Quincy St., Cambridge.	Astron. and Meteor.	1840–'44	. .	. .
8	Lilla-Edet, Sweden.	Total Solar Eclipse.	1851	. .	. .
9	Shelbyville, Ky.	" " "	1869	. .	. .
10	Jerez, Spain.	" " "	1870	. .	. .
11	Colorado Springs, Col.	Astron. and Meteor.	1887	6,000	. .
12	Seven Lakes, Col.	" " "	1887	11,000	. .
13	Pike's Peak, Col.	" " "	1887	14,134	. .
14	Willows, Cal.	Total Solar Eclipse.	1889	. .	D, I, J.
15	Wilson's Peak, Cal.	Astron. and Meteor.	1889, '90	6,000	I, J.
16	Chosica, Peru.	" " "	1889, '90	6,500	C, D.
17	Mollendo, Peru.	Meteorological.	1888–'90	100	. .
18	Vincocaya, Peru.	"	1888–'90	14,600	. .
19	Puno, Peru.	"	1888	12,500	. .
20	Pampa Central, Chile.	Photometric.	1890	. .	C.
21	Arequipa, Peru.	"	1890	8,000	C.
22	La Joya, Peru.	Meteorological.	1892	4,150	. .

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PRINCIPAL ASTRONOMICAL INSTRUMENTS.

Desig. Letter.	Instrument.	Aperture.	Visual or Photographic.	Maker.	Mounted.	Stations.
		inches.				
A	Refractor.	15	Vis.	Merz.	1847	1
B	Meridian Circle.	8, 8, 8	Vis.	Simms.	1870	1
C	Meridian Photometer.	4, 4	Vis.	Clark.	1882	1, 16, 20, 21
D	Doublet.	8, 8	Phot.	Clark.	1885	1, 14, 16, 5
E	Refractor.	11	Vis., Phot.	Clark.	1886	1
F	Reflector.	28	Vis., Phot.	Draper.	1887	1
G	Reflector.	15	Vis., Phot.	Draper.	1887	1
H	Refractor.	12	Vis.	Clark.	1887	1, 11, 12, 13
I	Refractor.	13	Vis., Phot.	Clark.	1887	1, 14, 15, 5
J	Doublet.	8, 10	Phot.	Clark.	1887	1, 14, 15
K	Doublet.	8, 8	Phot.	Clark.	1889	1
L	Refractor.	8	Vis.	Clark.	1890	1, 5
M	Reflector.	20	Vis., Phot.	Common.	1890	1, 5
N	Transit Photometer.	5, 5	Phot.	. . .	1881	1
O	Doublet.	24, 24	Phot.	Clark.	1893	1
P	Refractor.	10	Vis., Phot.	Clark.	1893	1

Several large prisms, having angles of from 5° to 15°, have been procured for use in photographing the spectra of the stars. One of these has an aperture of 24 inches, four have apertures of 11 inches, and four of 8 inches.

Numerous other telescopes of 6 inches aperture or less are not enumerated above.

LIST OF ANNALS.

Vol. I. Part I.	History and Description of the Observatory, 1840–1855.
" " " II.	Zone Catalogue. Dec. 0° 0′ to + 0° 20′.
Vol. II. Part I.	Observations of the Planet Saturn.
" " " II.	Zone Catalogue. Dec. + 0° 20′ to + 0° 40′.
Vol. III.	Account of the Great Comet of 1858.
Vol. IV. Part I.	Catalogue of Standard Stars.
" " " II.	Observed Right Ascensions of 505 Stars.
Vol. V.	Observations of the Great Nebula of Orion.
Vol. VI.	Zone Catalogue. Dec. + 0° 40′ to 1° 0′.
Vol. VII.	Observations of Solar Spots.
Vol. VIII. Part I.	Historical Account of the Observatory, 1855–1876.
" " " II.	Astronomical Engravings.
Vol. IX.	Photometric Researches, 1872–1875.

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Vol. X.	Meridian Circle Observations, 1871–1872.
Vol. XI.	Photometric Observations, 1877–1879.
Vol. XII.	Meridian Circle Observations, 1874–1875.
Vol. XIII. Part I.	Micrometric Measurements, 1866–1881.
" " " II.	Photometric Zone Observations, 1882–1886.
Vol. XIV.	Observations with the Meridian Photometer,
Vol. XV. Part I.	Catalogue of 1213 Stars. [1879–1882.
" " " II.	Zone Catalogue of 8627 Stars.
Vol. XVI.	Observations of Fundamental Stars, 1870–1886.
Vol. XVII.	The Almucantar, 1884–1885.
Vol. XVIII.	Miscellaneous Researches.
Vol. XIX. Part I.	Meteorological Observations, 1840–1888.
" " " II.	Zodiacal Light and Atmospheric Absorption.
Vol. XX. Part I.	Blue Hill Met. Observations, 1887.
" " " II.	Blue Hill Met. Observations, 1888.
Vol. XXI. Part I.	Observations of N. E. Met. Society, 1888.
" " " II.	Investigations of N. E. Met. Society, 1889.
Vol. XXII.	Meteorological Observations on Pike's Peak.
Vol. XXIII. Part I.	Discussion of Obs. with Meridian Photometer.
Vol. XXIV.	Results of Obs. with Meridian Photometer.
Vol. XXV.	Comparison of Positions of Stars.
Vol. XXVI. Part I.	Preparation and Discussion of Draper Catalogue.
Vol. XXVII.	Draper Catalogue of Stellar Spectra.
Vol. XXIX.	Miscellaneous Researches.
Vol. XXX. Part I.	Blue Hill Met. Observations, 1889.
" " " II.	Blue Hill Met. Observations, 1890.
" " " III.	Blue Hill Cloud Measurements.
Vol. XXXI. Part I.	Investigations of N. E. Met. Society, 1890.
" " " II.	Investigations of N. E. Met. Society, 1891.
Vol. XL. Part I.	Blue Hill Met. Observations, 1891.

The following investigations are still unpublished: —

Photometric observations of Jupiter's satellites while undergoing eclipse. 1879–1893.

Observations of variable stars of long period throughout their variation. 1889–1893.

Meridian Circle observations of 7959 stars between $-9^{\circ}\ 50'$ and $-14^{\circ}\ 10'$. 1888–1892.

Determination of the brightness, according to the Meridian Photometer, of about 8000 stars south of -30°. 1889–1891.

Determination of the brightness, according to the Meridian Photometer, of about 7000 stars north of -45°, including all stars of the sixth magnitude and brighter, comparison stars for variables, etc. 1891–1893.

Spectra of all stars brighter than the eighth magnitude, from the north to the south pole.

Catalogue of all stars having peculiar spectra.

Detailed study of the spectra of the brighter stars.

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Compliments of the Author.

The Planet Jupiter and its Satellites.

WILLIAM H. PICKERING.

Reprint from ASTRONOMY AND ASTRO-PHYSICS, No. 113.

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THE PLANET JUPITER AND ITS SATELLITES.*

WILLIAM H. PICKERING.

Advantage was taken of the past favorable opposition to make a careful study of this planet, and of each of the well known members of its family. Owing to the small size of our telescope, it has been impossible to observe Mr. Barnard's recently discovered satellite, but the steadiness of our atmosphere has enabled us to study the other members of the system under very favorable circumstances.

JUPITER.

The first subject which absorbed our attention was an investigation of the nature and appearance of the spots and belts. Various magnifying powers were employed, but 450 diameters gave, on the whole, the best results. Under the most favorable visual conditions, it appeared that the surface of the planet consisted of a uniform white mass of cloud, and that over this stretched a thin, gauzy veil of a brown material, in structure not unlike our cirrus clouds. This covered the entire surface of the planet from pole to pole, but was more dense in some places than in others. Where it occurred in dense masses it formed the belts, where it was thin, we had the spaces between them. Occasionally a round or elliptical hole of 1″ to 2″ in diameter, penetrated this layer. If the hole occurred in a belt, it was very conspicuous, but if it occurred between the belts, it was much less so. These holes are the well known white spots upon Jupiter, and are, with one or two exceptions, the only regions that appear entirely clear of the gauzy veil above mentioned. As the white spots seemed to occur indifferently either in or between the belts, it was inferred that they had their origin in the uniform white layer of the planet, and penetrated the cirrus layer from below. There was one narrow white streak parallel to the belts, and not over 1″ in breadth, where the cirrus layer was so attenuated that we

* Communicated by the author.

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could not be sure that it existed at all, but this region apparently differed from the other spaces only in degree and not in kind. The great red spot itself was extremely faint, and with difficulty distinguished. The space above it, however, excepting at its following end, was entirely clear of the cirrus formation, and thus indicated its whereabouts. The spot was, in fact, apparently seen through a hole in the cirrus as if it formed a portion of the white surface beneath. In short, it appears that were it not for this insignificant light gauzy veil of brown cloud, we should find the surface of Jupiter, like that of most of the other planets in the solar system, almost a perfect blank. This gauzy structure must float in a nearly transparent atmosphere surrounding and rising above it, and it is this atmosphere which causes the absorption, and which almost completely obscures the belts at the limb of the planet. A further reference to this atmosphere will be made later on, in describing the phenomena of the satellites.

THE SATELLITES.

We may classify the physical peculiarities of these bodies in the order of the facility with which they may be detected.

(*a*). *Relative Brightness.* The smallest telescope will show that the 3d satellite is the brightest of the four. The others follow in the order 1st, 2d and 4th. Under certain circumstances, as will appear later, the 2d may equal the 1st. Otherwise we have never detected any change in this order. Their mean magnitudes, as given in the Harvard Observatory Annals, Vol. XI, p. 276, are 5.2, 5.6, 5.8 and 6.4.

(*b*). *Size.* It requires a much more powerful telescope to clearly see the discs of the satellites. With such an instrument it is found that the 3d is the largest of them that the 4th is a little inferior to it, and that the two others are much smaller, and follow in the order, 1st, 2d. From this it follows that the 4th is very much darker colored than the other three.

(*c*). *Color.* These observations require a large telescope and a very clear atmosphere. Taking the color of Jupiter between the belts as our standard of white, the 1st and 2d satellites may be described as golden yellow. They are in general almost precisely the same color, but if there is any difference between them the 2d inclines more to green. The 3d is of a greenish yellow color quite different from the other two. On one occasion recently I saw the 2d half way in color between the 1st and 3d. The 4th is dark greenish grey and strikingly darker than the other three. As these are all non-actinic colors, this explains the fact that it requires from two to four times the exposure to secure a satisfac-

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tory enlargement of the satellites, that it does to obtain an enlargement of Jupiter itself upon the same scale. Also, that while the 1st and 2d are intrinsically the brightest to the eye, that the 3d requires the shortest exposure photographically.

(*d*). *Phase.* We now come to an observation of which only the most favorably located telescopes are capable, that of watching the change of shape as the satellite enters the shadow of its primary. The difficulty of course increases in the inverse order of the size of the satellite.

(*e*). *Diffraction Spot.* This phenomenon was first noticed at this Observatory in August 1891, and was described in the *Astr. Nach.* 3079. It consists of a black spot visible upon the surface of the satellite, and apparently due to diffraction. If the lens is in perfect adjustment, it is central, otherwise it appears near the edge of the disc. If the seeing is very good the spot is very small but increases in size as the character of the definition diminishes. Its appearance undoubtedly depends more or less upon the size of the satellite and of the objective. We frequently see it upon the 3d satellite, occasionally upon the 4th, but rarely upon the 1st or 2d. Unless all of the above described phenomena can be clearly seen it is probably useless for the observer to attempt to detect those that follow. Neither should he make the attempt with a power much lower than 700 diameters. He should also adjust his objective, if necessary, so that it shall not give the least trace of a wing under the highest power, even when thrown slightly out of focus. Possibly the best way of introducing our results will be to give a brief history of the observations that led up to them.

Upon October 8th of the past year, I began a series of measurements with the 13-inch telescope of the diameters of Jupiter's satellites. Upon the next evening, I undertook to measure the 1st, when at the first glance I noticed to my surprise that its disc was not circular, but very elliptical. A brief computation the next morning showed that if my measurements were correct, that the polar flattening would correspond to a rotation period of about forty minutes, assuming a uniform density. Observations upon the next evening confirmed my first measurements. Some of the other satellites were also measured and I then returned to the first one, when to my astonishment, instead of showing an elliptical disc, it showed one that was perfectly circular, precisely like the other satellites. I could scarcely believe my eyes, but as I continued to watch and measure, I saw the disc gradually lengthen again and assume the elliptical form, and I then understood what had really been found. The 1st satellite has the form of a prolate spheroid or ellipsoid, or in popular par-

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lance is "egg-shaped." The two minor axes are approximately equal, and the satellite revolves about one of them, or as we may say, it revolves "end over end." Within a few days, after this observation had been satisfactorily confirmed, it, with some facts pertaining to the other satellites, was cabled to the States, and published in the *New York Herald.*

Within a week from the date of my first observation, each of the other satellites had been recorded at some time as presenting an elliptical disc. But now a new difficulty arose,—in their cases the ellipticity was much less marked than in the case of the 1st satellite, and my assistant, Mr. Douglass, while readily confirming the ellipticity of the 1st, declared that the others always appeared to him to be circular. Nor was this all, the main difficulty lay in the fact that the three outer satellites when elliptical, appeared shortened equatorially, not lengthened, and this result was confirmed by the micrometer. In other words, these three satellites do not seem to revolve about their minor axes! Their rotation, therefore appears to contradict one of the most elementary principles of physics. It is chiefly for this reason that I have refrained from making any publication since my first telegram. I at first assumed that the result was due to an optical illusion, and tried various experiments, such as using the two eyes alternately, and turning the head through an angle of ninety degrees. The elongation nevertheless remained persistently in the same direction. I next thought the effect might be due to light and dark spots, suitably placed upon the surface. But when the satellites are in transit, and about disappearing, these spots should become visible. Nothing of the sort is seen, however, although surface markings have been discovered upon the 1st, 3d and 4th satellites. It was next suggested that the axes of the satellites might be greatly inclined to the plane of their orbits, and thus cause, not a shortening of the assumed equatorial, but an apparent lengthening of the assumed polar diameter, thus producing the same effect on the eye. The micrometer negatived this theory. Of late, probably owing to training of his eye, Mr. Douglass has been able to confirm my observations upon the three outer satellites, and we now both see them elliptical at the same times, and our position angles agree with one another within a few degrees. A possible explanation of their shape and revolution that has occurred to me is that of an irregular distribution of density in their interiors. This explanation seems improbable, and I therefore merely announce the facts that:

(*a*). The 1st satellite is a prolate ellipsoid revolving about one of its minor axes in a period of $13^h\ 03^m.0$.

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(*b*). The discs of the 2d, 3d, and 4th satellites at regular intervals assume the form of ellipses, and this periodic change is presumably produced by a rotation upon their axes.

In dealing with further details the satellites may best be taken up separately:

First Satellite.—The period of rotation of this satellite, as above stated, is $13^h\ 03^m.0$, and this result has been abundantly confirmed by repeated prediction and verification of its ephemeris. It follows from its shape as above described that its disc appears perfectly circular once every six and a half hours. This appearance lasts for half an hour. The remainder of the time it appears more or less elliptical. When at a maximum the major axis exceeds the minor by about ten per cent. Under these circumstances it will be seen that the ellipticity is considerably greater than that of Jupiter. Its equator is inclined to the plane of its orbit a trifle over ten degrees, and the precession of its equinoxes occurs with extraordinary rapidity. A complete revolution probably takes place in about twenty-six days, but further observations are required to make this determination conclusive. The disc bears one or more nearly longitudinal narrow dark markings. The following ephemeris for the month of March, 1893, gives the approximate Greenwich Mean Time at which the satellite assumes the circular phase, and is therefore at minimum brightness:

FIRST SATELLITE.

d	h	m	d	h	m	d	h	m	d	h	m	d	h	m
1	02	03	7	08	07	13	14	11	19	20	16	26	02	21
1	08	34	7	14	39	13	20	43	20	02	47	26	08	52
1	15	05	7	21	10	14	03	15	20	09	19	26	15	24
1	21	37	8	03	41	14	09	46	20	15	51	26	21	56
2	04	09	8	10	13	14	16	17	20	22	22	27	04	27
2	10	40	8	16	45	14	22	49	21	04	53	27	10	58
2	17	11	8	23	16	15	05	21	21	11	25	27	17	30
2	23	43	9	05	47	15	11	52	21	17	57	28	00	02
3	06	15	9	12	19	15	18	23	22	00	28	28	06	33
3	12	46	9	18	51	16	00	55	22	06	59	28	13	04
3	19	17	10	01	22	16	07	27	22	13	31	28	19	36
4	01	49	10	07	53	16	13	58	22	20	03	29	02	08
4	08	21	10	14	25	16	20	29	23	02	34	29	08	39
4	14	52	10	20	57	17	03	01	23	09	05	29	15	10
4	21	23	11	03	28	17	09	33	23	15	37	29	21	42
5	03	55	11	09	59	17	16	04	23	22	09	30	04	14
5	10	27	11	16	31	17	22	35	24	04	40	30	10	45
5	16	58	11	23	03	18	05	07	24	11	11	30	17	16
5	23	29	12	05	34	18	11	39	24	17	43	30	23	48
6	06	01	12	12	05	18	18	10	25	00	15	31	06	20
6	12	33	12	18	37	19	00	41	25	06	46	31	12	51
6	19	04	13	01	09	19	07	13	25	13	18	31	19	22
7	01	35	13	07	40	19	13	45	25	19	50			

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Second Satellite.—This satellite has given us more trouble than any of the others, and has proved to be a very difficult object to observe. At times it appears circular, and at times slightly elliptical. Sometimes the major-axis lies in the direction of the orbit, and at other times at right angles to it. This appearance has been further confirmed by micrometric measurements. The ellipticity is decidedly less than that of the 1st satellite. Its shape in short appears to be that of an ellipsoid of three unequal axes, revolving about the middle one. Its equator lies in the plane of its orbit. No surface markings have been detected upon it. Its period of rotation is $41^h\ 24^m$, or about an hour short of the time required to complete half a revolution in its orbit.

A curious observation was made in connection with this satellite upon the night of December 11. The satellite was about to be occulted, and was decidedly shortened equatorially at the time. Owing to the inclination of its orbit to the line of sight it did not pass behind the center of the planet, but somewhat above it, the position angle between the point of contact and the planet's equator being estimated at about thirty degrees. The satellite retained its shape until almost in contact with the limb, when the major axis of its ellipse suddenly changed its position angle through thirty degrees, becoming parallel to the limb of the planet. Now the interest of this observation lies in the fact that this is just the sort of change that we should expect would be produced if Jupiter were surrounded by a comparativcly rare atmosphere, extending several hundreds of miles above its surface, such as presumably extends several thousand miles above the suface of the Sun and thirty or forty miles above that of the Earth. The observation is a very difficult one, however, and whether the change of shape was real or only apparent must be settled by subsequent research.

The following ephemeris for the month of March, 1893, gives the approximate Greenwich mean time at which this satellite presents the smaller of its two elliptical phases, that is, the one in which the minor axis is parallel to the plane of its orbit. Under these circumstances it shines with its minimum brilliancy.

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SECOND SATELLITE.

d	h	d	h	d	h	d	h
1	15.2	9	09.5	17	03.8	24	22.1
2	11.9	10	06.2	18	00.5	25	18.8
3	08.6	11	02.9	18	21.2	26	15.5
4	05.3	11	23.6	19	17.9	27	12.2
5	02.0	12	20.3	20	14.6	28	08.9
5	22.7	13	17.0	21	11.3	29	05.6
6	19.4	14	13.7	22	08.0	30	02.3
7	16.1	15	10.4	23	04.7	30	23.0
8	12.8	16	07.1	24	01.4	31	19.7

Third Satellite.—On account of its size and brightness this is much the easiest satellite to observe. Indeed even the occasionally elliptical shape of its disc has been noted by Lassell, Secchi and Burton. None of these observers, however, seem to have been able to repeat their observations with sufficient frequency or precision to construct an ephemeris from them, or determine the inclination of the axis. When the disc is most elliptical the major axis exceeds the minor by about 0″.2, a very appreciable quantity. The satellite appears to be of the shape of an oblate spheroid (like a watch), revolving about one of its major axes. Its equator is inclined about eighteen degrees to the plane of its orbit, and it presents the elliptical phase twice in each revolution about its primary. Like our Moon, therefore, its period of rotation coincides, at least approximately, with that of its revolution in its orbit. The time at which it reaches its maximum ellipticity occurs thirty-four hours after inferior and superior conjunction. Its surface markings are readily seen, especially during transit, the most conspicuous being a dark belt situated in the northern hemisphere, and inclined about fifteen degrees to its orbit. The position angle of the belt was determined upon a different date from that of the direction of the minor axis of the ellipse, and it is quite possible that the two are really parallel. There is some evidence also, from the shape of the belt that the south, pole of the satellite is inclined towards us ten or more degrees, which would materially increase the inclination of its equator to its orbit. There are also indications of a rapid precession, since the position angle of its major axis appears to vary. Various dark lines and shadings spread southward from the belt, some of them uniting in part, at least, to form a southern belt parallel to the northern one, but less strongly marked. At times the southern pole has appeared somewhat brighter than the rest of the surface, but never brilliant as in the case of Mars. Like our

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Moon and Mars the limb is rather brighter than the center of the disc. The following ephemeris, constructed like the preceding ones, indicates the time at which the satellite presents the maximum elliptical phase, and when it is consequently at minimum brilliancy during the month of March, 1893:

THIRD SATELLITE.

d	h	d	h	d	h	d	h
2	06						
5	20	13	00	20	05	27	09
9	10	16	14	23	19	30	23

Fourth Satellite.—This satellite usually presents a circular disc, but at conjunction with Jupiter it is elliptical, the major axis lying nearly perpendicular to its orbit. Its periods of rotation and orbital revolution are therefore identical. Its color is so dark that its surface markings are only seen with the greatest difficulty. They seem to consist chiefly of a broad, dark equatorial belt, the poles being slightly lighter and more greenish in color. The north pole has been seen much brighter than the south, but is not always so. Occasionally it has been thought that very minute dark and light spots have been detected upon its disc, the latter near the north pole. Webb states that he frequently has seen the 4th satellite surpass the 3d in brightness. Such an observation would certainly be of the greatest interest at the present time, and could only be accounted for either by the third becoming still darker in color than the fourth is at present, or by extensive white spots appearing upon the fourth, which latter hypothesis seems the more probable of the two. This satellite will exhibit a slight minimum of brilliancy upon the nights of March 8, 17, and 25.

At times the discs of the satellites have seemed to be of a slightly irregular shape. That is to say, one side of the so-called ellipse has seemed flatter than the other. This has been particularly noticed by Mr. Douglas, though I have occasionally seen it also. I am not inclined to consider it a genuine phenomenon, but rather due to some local cause, such as the action of the wind, combined with slightly inferior definition. No striking instances of change in intrinsic brilliancy from night to night have been noticed in our observations of the satellites, their colors and light not seeming to us more variable in general than that of the other members of the solar system. As far, therefore, as our observa-

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tions go, I should be inclined to attribute most of the varying phenomena of light and dark transits to variations in the light reflected to us by the clouds on Jupiter, rather than to variations in the brightness of the satellites themselves.

Our micrometric measurements of the diameters have not as yet been completely reduced, but I may say that they confirm those of Engelmann, diminishing the size of each satellite possibly about two hundred miles. This, while increasing their densities slightly, still leaves them at an extraordinarily low figure. Taking the specific gravity of water as our standard, the density of the 1st satellite is less than 1.5, and the density of the 2d, less than 2.5. The densities of the 3rd and 4th satellites lie between these figures. As our telescopic definition is perfect, I do not see how it is possible for these results to be in error. That being admitted, the question arises of what can these bodies be composed? As shown in my paper published in ASTRONOMY for November, 1892, they are too small and too light to retain an atmosphere, excepting at a very low temperature, a temperature, in fact, which could not be very far above that of absolute zero. A low temperature is perhaps not improbable, but of what must the clouds be composed that form their visible surface? If the clouds are formed of liquid drops or bubbles, this liquid can certainly not be water. Besides, these clouds are not white when compared with those upon Jupiter. Shall we conclude that these are clouds of condensed oxygen, nitrogen, or hydrogen? If this hypothesis, taking into consideration the blackness of the 4th satellite, seems improbable, and we dismiss the atmospheric theory altogether, the only solids which are light enough for our purpose, exclusive of the alkaline elements, are those that are porous or hollow. There is still one course left open to us, however. It is that each of these satellites is nothing more than a very condensed swarm of meteorites, like Saturn's ring. The apparent revolution of the 3d satellite about its major axis, which is certainly not a difficult observation to repeat, indicates pretty clearly that there is something peculiar about these bodies, and it is possible that their real constitution may yet admit of mathematical demonstration.

Although it is quite probable that the number of astronomers who will have the optical means to confirm all of these observations is rather limited, yet there is one test that is within the reach of nearly everyone. This depends upon the fact that when the 1st satellite presents a circular disc, and the 2d is elongated equatorially, that there is very little difference between them in

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brightness, and that, on the other hand, when the reverse conditions prevail, the difference between them is quite marked. The following ephemeris for March has therefore been prepared, Greenwich mean time being employed as before. Upon those dates marked with an * the 1st and 2d satellites will be found to be of approximately equal brightness. Upon those dates marked with a † the 1st satellite will conspicuously excel the 2d in brilliancy.

FIRST AND SECOND SATELLITES.

d	h	d	h	d	h	d	h
2	23.5*	9	09.2†	18	01.5†	24	01.4†
3	09.2†	9	19.2*	18	11.3*	24	11.4*
3	19.2*	12	20.7†	18	21.3†	24	21.3†
4	05.2†	13	07.3*	19	07.4*	28	09.5†
4	15.1*	13	17.3†	19	17.3†	28	19.5*
8	03.4*	14	03.3*	20	03.1*	29	05.5†
8	13.2†	14	13.2†	23	05.4†	29	15.4*
8	23.2*	14	23.6*	28	15.4†	30	01.4†

It is suggested that early observations of the relative brightness of these two bodies may be employed to determine their periods of rotation with considerable accuracy.

AREQUIPA, Peru, Jan. 2, 1898.

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ω CENTAURI.

SOLON I. BAILEY.

Reprint from ASTRONOMY AND ASTRO-PHYSICS, No. 118.

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ω CENTAURI.*

SOLON I. BAILEY.

The cluster ω Centauri lies just within the northern border of the Milky Way at R. A. $13^h\ 19^m\ 16^s$; Dec. $-46°\ 49'.5$ (1875, Gould).

All the stars within a radius of 5° are of the sixth magnitude or fainter. To the naked eye the cluster appears as a hazy star of less than the fourth magnitude. In a field-glass, it becomes a globular mass of nebulous light, dense at the centre, and gently fading away at the border. The globular form is in general very perfect, but to the north it appears slightly flattened. With a telescope of high power it becomes a maze of faint stars, well defined and separated, but projected, toward the center of the cluster, upon a background of faint nebulous light. Some interesting photographs of this cluster have been made recently with the Boyden telescope of 13-in. aperture and 16 feet focal length. A brief study has been made of the number and distribution of the stars composing this group as shown on one of these photographs. The plate was made May 19, 1893, and the exposure was two hours. The 8-in. finder, which had been previously used for purposes of following, was found after many trials to be incapable of giving sufficiently exact results for this work, and an eyepiece was inserted into the field of the main telescope itself. By this means the photographic images were greatly improved. The precise limits of the cluster are hard to define, but for the purposes of this study a region 30′ square was taken, having for its centre the centre of the cluster. As may be seen from the diagram giving the enumeration, the cluster fills this region fairly well and perhaps extends a little beyond. Within this region is no star so bright as the eight magnitude. A field-glass of good power shows no individual star. Within this region Dr. Gould in his "Zones" gives seven stars: 13 h. 1083, 1095, 1108, 1164, 1232, 1235 and 1240. The magnitudes given are respectively 8½, 8½,

* Communicated by Edward C Pickering Director of the Harvard College Observatory.

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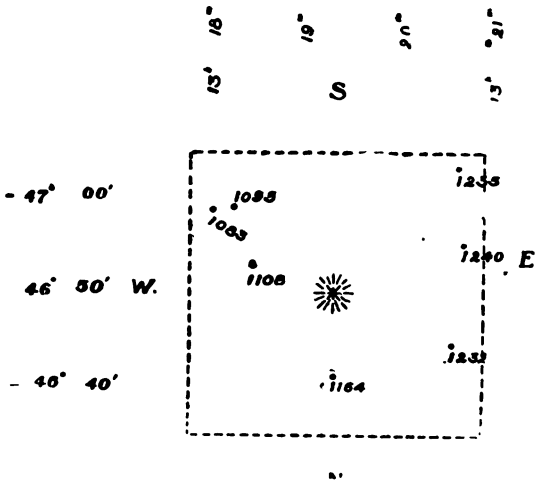
9½, 8, 9, 9, 9. The position of these stars in respect to the centre of the cluster is shown in diagram 1. They are found on the photograph in squares Ea, Eb, Id, Pk, Ms, As, and Gs. (Diagram 2). They include all the brighter stars of the cluster. The magnitudes now correspond fairly well with those given above, with the exception of 1095. My estimates of the visual magnitudes are 8.7, 9.5, 8.8, 8.5, 9, 8.8, 9.2. In the zones, 1095 is given equal in brightness to the close star 1083. It is now nearly a magnitude fainter and may be a variable. Photographically, 1108 is about the same brightness as 1164 and 1235 is brighter than 1083.

DIAGRAM 1.



For the purpose of the count, a series of black lines were drawn on white paper, one centimetre apart. Four hundred squares were thus formed. This was then photographically reduced on glass and a glass print made giving a transparent field with fine dark lines. The size of this recticule was 4.4 c. m., and its scale was such that the region covered was 30′ square, each little square having for its side 90″ of arc.

This reticule was placed over the negative, the whole placed in a frame having proper illumination and the number of stars in each square counted. A compound microscope, with a magnifying power of 40 diameters, was used. The cross-hairs of the eyepiece divided each square into four sub-squares, which served

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to prevent confusion in counting. By estimate the photographic stellar images, except in the case of a few of the brighter stars, differed very little from 4″ in diameter. With the magnifying power used, the images had a slightly elliptical form, which, however, proved an advantage as it enabled the star images to be distinguished from any possible imperfections in the plate.

DIAGRAM 2.

S

	63	78	110	146	201	280	335	470	637	681	672	632	506	476	336	253	185	141	104	83	6389
A	2	2	2	4	3	1	4	4	6	3	2	3	6	3	7	5	6	6	3	3	75
B	2	4	5	3	4	4	4	4	4	3	6	5	6	5	10	6	7	3	4	3	92
C	2	2	4	7	10	8	4	8	4	9	8	10	8	10	7	6	5	10	4	2	128
D	2	0	2	6	5	4	7	6	10	10	12	14	6	12	4	10	6	4	4	8	132
E	4	2	6	6	10	6	9	10	10	18	26	18	11	19	7	7	12	6	4	6	197
F	3	2	5	6	6	14	14	19	19	22	23	24	26	25	11	12	3	5	5	4	248
G	5	6	8	6	9	12	25	26	34	47	34	44	32	38	16	12	13	8	10	7	392
H	5	6	6	16	10	20	26	30	52	54	58	59	44	46	27	26	14	14	7	4	524
I	6	8	8	10	21	28	37	60	75	81	66	74	62	58	44	20	10	9	4	8	689
W J	3	4	7	12	14	31	46	65	89	91	98	92	71	62	42	24	10	6	6	4	777 E
K	4	6	13	18	21	34	40	62	88	100	96	80	60	54	35	27	16	15	6	6	781
L	2	10	5	9	14	38	33	52	77	74	83	68	48	42	44	27	25	6	8	8	673
M	2	6	5	13	13	26	26	40	62	71	62	58	38	32	24	16	16	14	10	4	538
N	6	3	10	10	18	22	18	28	38	32	29	29	32	20	8	16	10	12	6	1	348
O	3	5	4	4	10	12	12	18	30	28	21	20	18	14	12	12	8	6	4	8	249
P	3	6	4	4	5	4	5	16	10	18	14	10	12	9	12	7	8	4	4	1	156
Q	4	1	8	6	6	4	8	9	12	6	12	10	10	6	12	8	5	5	6	2	140
R	0	2	4	1	8	7	9	8	9	6	10	8	8	8	6	10	4	5	4	2	119
S	4	1	3	3	10	4	2	3	5	6	4	2	2	3	4	0	1	3	2	2	64
T	1	2	1	2	4	1	6	2	3	2	8	4	6	10	4	2	6	0	3	0	67
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	6389

N

All objects not of this form were rejected. Toward the center of the cluster, counting was somewhat difficult, but doubtful objects were discarded. The numbers given do not represent the full number of stars that left their impression on the plate. Toward the center of the cluster, the background between the distinct images was of a faintly mottled gray, apparently due to stars too faint and closely packed to make distinct records. No account was made of this background except where it became sufficiently differentiated to assume the peculiar form referred to above.

Near the center of the cluster, chiefly in square Jj, occurs a peculiar break in the brighter stars. The number is preserved, however, since there is a background of fainter stars.

Diagram 2 shows the number of stars counted in each square. The sums at the side and top show in a general way the condensation toward the center. The cluster was counted independently, twice, once by Mrs. Bailey and once by myself. The

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results obtained were 6402 and 6373 stars respectively. The disagreement arose from the fainter mottled background, as the negative showed every gradation from a nearly even shading to a decided mottling. This appearance seems to be due to close faint stars rather than to nebulous matter. The numbers given in the squares are the means of the two counts, and the sum of the means, 6389 stars, may be safely assumed to be the approximate number of stars that made distinct impressions on this plate.

There can be no doubt, however, that the whole number of stars comprising this splendid cluster is very much greater.

AREQUIPA. Peru.
June 30, 1893.

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Stars Having Peculiar Spectra.

M. FLEMING.

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STARS HAVING PECULIAR SPECTRA.*

M. FLEMING.

A recent examination of photographs of stellar spectra lately received from the Peruvian station of the Harvard College Observatory and taken under the direction of Professor W. H. Pickering, has added five faint objects, in the constellation Argo, to the list of stars having spectra of the fifth type, and similar to the bright line stars in Cygnus. As forty of these objects have already been announced, this increases the known number to forty-five. The designation of the star, its approximate right ascension and declination for 1900 and its magnitude are given in the first four columns of the following table. The Galactic longitude and latitude are given in the fifth and sixth columns.

Designation.	R. A. 1900 h m	Dec. 1900 °	Magn.	G. Long. °	G. Lat. °
——	10 7.6	−60 8	...	252 4	−3 30
A. G. C. 14691	10 40.3	−59 12	8½	255 48	−0 40
——	10 43.4	−58 41	...	255 20	−0 1
A. G. C. 14965	10 52.0	−59 51	8½	256 49	−0 38
——	10 55.8	−57 17	...	256 16	+1 56

In addition to the stars of the fifth type mentioned above, six new variables have been discovered from the photographs received from Peru and one from those taken in Cambridge during July. Their spectra are of the third type having also the hydrogen lines bright, as is the case in the spectrum of *o* Ceti and other variables of long period. A table of these is here given with further details regarding the measurements following it. The constellation is given in the first column and this is followed by the approximate right ascension and declination for 1900 of the variable. The next two columns give the greatest and least brightness as measured from the photographs. The date on which its spectrum was photographed is contained in the last column.

Constellation.	R. A. 1900 h m	Dec. 1900 °	Gr. Br.	Lt. Br.	Date.
Horologium	2 49.7	−50 21	6.2	9.7	Sept. 10, 1891
Octans	5 56.8	−86 26	7.4	< 11.3	Sept. 11, 1891
Bootis	14 22.3	+5 7	8.2	10.7	April 26, 1892
Libra	15 18.5	−22 34	8.4	< 11.0	July 25, 1891
Octans	17 25.9	−86 46	8.2	< 11.7	Aug. 31, 1891
Sagittarius	19 49.7	−29 26	7.5	< 12.6	Oct. 3, 1881
Tucana	23 52.2	−65 56	10.2	< 12.6	Aug. 25, 1892

* Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

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The variable star in Horologium in R. A. $2^h\ 49.7^m$, Dec. $-\ 50°\ 21'$, was measured on photographs taken on Aug. 21, Aug. 25, Aug. 28, Sept. 7, Sept. 26, Nov. 3, 1889, Sept. 8, 1890, Sept. 10 and Sept. 11, 1891, and gave the magnitudes 9.6, 7.5, 7.6, 8.1, 9.3, 9.7, 7.7, 6.2 and 6.2 respectively.

The variable star in Bootis in R. A. $14^h\ 22.3^m$, Dec. $+\ 5°\ 7'$, was measured on photographs taken on May 19, 1890, May 23, 1891, April 26, May 17, May 24, June 6, June 10, June 12, June 15, July 6 and July 21, 1892, and gave the magnitudes 8.8, 8.2, 8.2, 8.4, 8.4, 8.8, 9.1, 8.9, 9.1, 10.0, and 10.7 respectively.

The variable star in Libra in R. A. $15^h\ 18.5^m$, Dec. $-\ 22°\ 34'$, was measured on photographs taken on June 4, June 7, June 19, July 6, July 12, July 12, July 22, 1889, March 30, May 29, 1890, May 16, May 16, June 3, June 3, June 3, June 25, July 14, 1891, May 24, June 21, July 12, July 18 and July 25, 1892, and gave the magnitudes 9.0, 9.2, 8.6, 8.5, 8.6, 8.6, 8.6, 9.5, < 11.0, 8.5, 8.4, 8.8, 8.9, 8.8, 9.7, 10.4, 9.9, 8.6, 8.6, 8.4 and 8.5 respectively.

The variable star in Sagittarius in R. A. $19^h\ 49.7^m$, Dec. $-\ 29°\ 26'$, was measured on photographs taken on June 10, June 20, July 8, July 21, Aug. 20, Aug. 22, Oct. 7, 1889, May 28, 1890, May 17, May 17, June 2, June 2, Aug. 11, Oct. 3, 1891, July 11, July 25, Aug. 16, Aug. 18 and Aug. 23, 1892, and gave the magnitudes 11.0, < 11.2, < 12.4, 12.4, 12.0, < 10.7, 11.1, 11.7, < 12.2, < 12.6, < 10.7, < 12.2, 11.0, 7.8, 10.8, 10.9, 8.0, 8.0, and 7.5 respectively.

The variable star in Tucana in R. A. $23^h\ 52.2^m$, Dec. $-\ 65°\ 56'$, was measured on photographs taken on Aug. 13, Sept. 20, Oct. 8, Nov. 28, 1889, July 25, Sept. 10, 1890, June 30, Aug. 25, Aug. 25, Sept. 17, Sept. 17, Oct. 4, Oct. 4, Oct. 5 and Oct. 26, 1891 and gave the magnitudes 10.8, < 11.1, < 11.3, < 12.1, < 12.6, < 12.2, < 10.0, 10.6, 10.3, 10.2, 10.3, 10.6, 10.5, 10.5 and 11.0 respectively.

The region including the variable star in Octans in R. A. $5^h\ 56.8^m$ Dec. $-\ 86°\ 26'$ was contained on one hundred and five photographs taken between May 9, 1889, and April 26, 1892, its magnitude being about 7.6 on the first date when it was probably near its maximum. At the following minimum it was fainter than the magnitude 11.0. It was again bright on June 22, 1890, and on Aug. 16 and Sept. 3, 1891, when its magnitude was 8.9, 8.2 and 8.2 respectively. Between these two maxima its minimum was fainter than 11.3 and on March 30 and April 26, 1892, it was fainter than the magnitude 10.8.

The region including the variable star in Octans in R. A. 17^h

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25.9^m, Dec. — 86° 46′, was contained on eighty-nine photographs taken between May 14, 1889, and April 26, 1892. On Aug. 29, 1889, its magnitude was 8.4 when it was probably near its maximum. At minimum it was fainter than 10.5. It was bright again an April 8, 1890, when its magnitude was 8.5. At minimum it was fainter than 11.7. On Sept. 20, 1891, it again attained the magnitude 8.4 and on March 30, 1892 it was fainter than the magnitude 10.5.

Photographs of the spectra of A. G. C. 9326, R. A. 7^h 14.8^m, Dec. — 36° 33′ (1900), Magn. 5.3, and of A. G. C. 10963, R. A. 8^h 9.7^m, Dec. — 35° 35′ (1900), magn. 5.3 taken on April 18, 1892, and on March 16, 1892, respectively, show the F line bright and place them in the same class with δ and μ Centauri.

The magnitudes given above depend on measures derived from the photographs by using the magnitudes of the comparison stars as given in the Argentine General Catalogue. Since all of these variables are probably red stars, as indicated by their class of spectrum, it will be necessary to apply to the magnitudes given above a correction for color before comparing them with magnitudes obtained from visual observations.

Interesting photographs have been obtained of the spectra of the two objects A. G. C. 6744, R. A. 5^h 39.4^m, Dec. — 69° 9′ (1900), magn. 6¼, and A. G. C. 20937 R. A. 15^h 21.9^m, Dec. — 24° 49′ (1900), magn. 8. The first of these is the well known gaseous nebula surrounding 30 Doradus. The photograph shows that its spectrum is unlike that of ordinary gaseous nebulæ. A. G. C. 20937 gives a spectrum which appears to be similar and is probably an object of the same class although its nebulous character has not hitherto been suspected. A photograph of the spectrum of G. C. 2581, R. A. 11^h 45.3^m, Dec. — 56° 37′ (1900), magn. 9½, showing bright lines was obtained on Aug. 2, 1892 at Arequipa in Peru. The research which has resulted in the discovery of the above list of objects forms part of the Henry Draper Memorial.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Oct. 10, 1892.

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Stars Having Peculiar Spectra.

M. FLEMING.

Reprint from ASTRONOMY AND ASTRO-PHYSICS, No. 112.

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STARS HAVING PECULIAR SPECTRA.*

M. FLEMING.

An examination of the photographs of stellar spectra received on December 6, 1892, from the Peruvian station of the Harvard College Observatory, and taken under the direction of Professor W. H. Pickering, has led to the discovery of the following objects of interest. The five stars given in the following table have spectra of the fifth type, consisting mainly of bright lines. This adds two more to the group of stars of this class in the constellation Argo, and increases the known number of these objects in the entire sky from forty-five to fifty, all of which are near the central line of the Milky Way. None of these five stars are catalogue stars. Their approximate right ascensions and declinations for 1900 are given, followed by their galactic longitudes and galactic latitudes.

R. A. 1900		Decl. 1900		G. Long.		G. Lat.	
h	m	°	′	°	′	°	′
10	13.3	− 57	24	251	14	− 0	48
10	47.9	− 61	46	257	5	− 2	36
11	55.2	− 54	33	263	29	+ 6	53
13	24.3	− 61	34	275	15	− 0	1
15	55.0	− 62	28	290	34	− 8	28

In addition to the objects in the above list, a star in Scorpius, whose approximate position for 1900 is in R. A. $16^h\ 56^m.8$ Dec. $-36°\ 40'$, was found to have the hydrogen lines bright in its photographic spectrum. As this is a property of many known variables of long period and has already led to the discovery of a number of new variables, chart plates containing the region of this star were at once examined and resulted in the confirmation of its variability. The plate on which the star was found was taken in August 1892. The exact date is not given since the record has not yet been received from Peru. The magnitudes < 12.9 12.4, < 11.4, < 11.4, 9.5. < 10.4, 11.3, 11.8, 11.3, 12.6, < 11.2, 10.5, 10.5, 10.4, 10.1, < 11.4, < 11.4, and 9.2 were derived from measures of photographs taken on June 3, June 21, July 9, July 13, 1889; March 25, May 9, June 14, June 21, June 23, Sept. 5, Sept. 6, 1890; May 18, May 18, May 20, May 20, 1891; May 17, May 17, and August, 1892, respectively. From an examination of spectrum plates taken at Cambridge B. D. $+ 9°$ 4369, R. A. $19^h\ 56^m.3$, Dec. $+ 9°\ 14'$ (1900) magn. 8.7, is shown to have a spectrum of the fourth type.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Jan. 11, 1893.

* Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

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STARS HAVING PECULIAR SPECTRA.

M. FLEMING.

From ASTRONOMY AND ASTRO-PHYSICS, No. 116.

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STARS HAVING PECULIAR SPECTRA.*

M. FLEMING.

A recent examination of photographs of stellar spectra taken at Cambridge, and at Arequipa, has resulted in the discovery of several interesting objects which are enumerated in the following table. The designation of the star is given in the first column and is followed by its approximate right ascension and declination for 1900, its magnitude, and a brief description of its photographic spectrum.

Designation.	R. A. 1900		Dec 1900		Magn.	Description.
	h	m	°			
B D. + 49° 41	0	12.2	+ 49	44	9.4	Type IV.
B. D. — 13° 893	4	24.5	— 13	17	5.8	F line bright.
A. G. C. 5429	4	43.8	— 36	23	7½	Type IV.
A. G. C. 11890	8	42.4	— 29	21	7½	Type IV. [bright).
—— ——	15	27.0	— 71	32	—	Type III (Hydrogen lines
A. G. C. 22838	16	47.9	— 44	50	8.2	Type V (Bright lines).
Z. C. XVIII^h 56	18	3.3	— 63	38	9½	Type III (Hydrogen lines
A. G. C. 26129	18	59.7	— 38	17	8½	Type IV? [bright).
B. D. — 21° 6376	23	6 3	— 21	32	9·0	Type IV.

A. G. C. 11890 was found by Mr. A. E. Douglass in an examination of the photographs taken in Peru before they were sent to Cambridge. This object is probably identical with No. 29 of the list published in the *Astronomische Nachrichten*, Vol. XCIX, 337, which is there erroneously announced as U. A. Pyxis, 34, magnitude 6.5. The spectrum of the latter star is of the second type.

The star of the ninth magnitude whose approximate position for 1900 is in R. A. 15^h 27.0^m, Dec. — 71° 32′ has a spectrum similar to that of variable stars of long period. The photographic charts of this region show a slight variation but the material is not sufficient to regard the variability as confirmed.

A.G.C. 22838 has a spectrum similar to that of the bright line stars in Cygnus and increases the known number of these objects to fifty-one. Its galactic longitude is — 2° 7′ and its galactic latitude is 308° 47′.

Z.C. XVIII^h 56 has a spectrum similar to other known variables of long period. Photographic charts of this region were therefore examined and resulted in the confirmation of variability of this star. Measurements of photographs, taken on August 8, August 13, August 20, September 4, 1889; June 12, June 12, 1891, and September 17, 1892, gave for it the photographic magnitudes 8.1, 8.1, 8.1, 9.0, 7.6, 7.6 and 7.9.

* Communicated by Edward C. Pickering, Director of Harvard College Observatory.

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Photographs have also been obtained of the spectra of U Virginis, V Boötis, S Geminorum, T Cassiopeiæ, R Piscis Austrini, and T Geminorum, which show them to be of the third type having the hydrogen lines bright. The photographic spectrum of the variable star of the fourth type, R Leporis, has also been obtained.

HARVARD COLLEGE OBSERVATORY,
May 10, 1893.

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Work for Large Telescopes.

EDWARD C. PICKERING.

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WORK FOR LARGE TELESCOPES.*

EDWARD C. PICKERING.

A wide popular interest is now felt in telescopes of the largest size. The general public has no doubt an inordinate idea of what they should show. Some persons, however, considering the great cost and supposed limited field of work of a large telescope, maintain that results of greater value might be reached by a different expenditure of money. Undoubtedly, in the United States, the capital invested in large telescopes is out of all proportion to the income available for keeping them at work, and perhaps on this account the results attained are less than might be expected. As difficulty is often found in providing suitable work for a large telescope, it may be worth while to enumerate some of the researches in which such an instrument might secure results which could not be obtained with a smaller instrument. As it is not easy to decide whether more useful results could de obtained visually or photographically, it would be a great mistake to make the instrument of such a form that it could not be used in both ways. This is readily done by making the front lens reversible, with surfaces of unequal curvature. The additional expense is slight, and the objection that the photographic field is diminished owing to the necessary separation of the lenses, is not important when the focal length is very great, since the available field is then larger than can be conveniently covered by a single photographic plate. The only large lens as yet used in this way has an aperture of thirteen inches, and is now at the Harvard station in Peru. The photographic results in California, and the visual results in Peru indicate that when employed in either way its definition is unsurpassed. The focal length of the instrument here proposed should be as great as possible. The Bruce photographic telescope will have such advantages over other instruments when a relatively short focal length is desired that competition with it in this respect would generally be undesirable. The focal length is likely to be limited by the mechanical difficulties and the expense of constructing a suitable dome. The optical difficulties diminish with the increase of focal length.

A telescope of the largest size, constructed so that it could be used either visually or photographically, and mounted in a location where the atmospheric conditions were favorable could be usefully employed on either of the twenty researches enumerated

* Communicated by the author.

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below. A portion of them have already been undertaken with the 15 and 13-inch telescopes at the Harvard stations at Cambridge and Arequipa. They should be extended to stars beyond the reach of the Harvard instruments.

1. Micrometric measures of close double stars. The great focal length should render the errors extremely small.

2. Micrometric measures of faint satellites.

3. Positions of comets only when beyond the reach of smaller instruments.

4. Diameter of planets, satellites and bright asteroids.

5. Approach and motion of all known gaseous nebulæ by visual observations of their spectra, as has been done in certain cases at the Lick Observatory.

6. Photometric measures of the light of faint stars selected as standards, including faint comparison stars for variables, stars selected from clusters, standards proposed by the Committee of the American Association (Proc. XXXIV, 1). The measures may be made with the aid of a wedge, a Zöllner photometer or an auxiliary telescope (Harvard Annals, XI, Part II, XIII, Part II).

7. Relative brightness of components of double stars (Harvard Annals, XI, Part I.

8. Photometric measures of Jupiter's satellites, while undergoing eclipse.

9. Measures of the intensity of the various portions of the brightest nebulæ, and the central portions of the fainter nebulæ. At Cambridge this is done by comparing with the image of a known star in an auxiliary telescope thrown out of focus by a measured amount. If the nebula has a stellar nucleus throw it also out of focus by a known amount. This gives the mean brightness of the vicinity of the nucleus. Apply the same method to comets. Measure clusters in the same way, throwing them out of focus until the separate stars are indistinguishable. This seems to indicate the density of the cluster, or ratio of the mean diameters of the stars to their distances apart.

10. Observations by Argelander's method of variables when too faint to be observed elsewhere.

11. Examination of all stars brighter than a given magnitude for faint and close companions.

12. Study of clusters in connection with photographs, to determine the number of stars in portions not resolved in the photographs (see No. 16).

13. Study of the surfaces of the Moon, planets and satellites with very high powers. This can be done usefully only if the location is such that the air is extremely steady.

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14. Search for faint planetary nebulæ, bright line stars (near central line of the Milky Way) and stars of the fourth type. Use a direct-vision prism or a prism of small angle near the focus with an eye-piece of very low power.

15. Study of the spectra of known nebulæ when large with a slit spectroscope, when small with the apparatus described in No. 14. Of the nine or ten thousand known nebulæ and clusters the spectra of about a hundred only are known to be gaseous and of a few hundred more to be continuous. The composition of all the rest is unknown. The spectra of some clusters may be peculiar.

16. Photograph doubles and all clusters coarse enough to be resolved, and measure the relative positions and brightness of the components.

17. Photograph Jupiter's satellites while undergoing eclipse. Move the plate in declination every 5 or 10 seconds thus obtaining a series of images.

18. Photograph the Moon and planets enlarging the image in the telescope by means of an eye-piece especially constructed for the purpose.

19. Measure the approach and recession of the stars from photographs of their spectra as has been done at the Potsdam Observatory.

20. Photograph the spectra of the coarse clusters and doubles with the apparatus described in No. 14. Short spectra with poor definition are thus obtained, but very faint stars can be photographed and the separation due to the great focal length will show to which type they belong, even if they are very closely crowded together.

The last five researches will be excluded if the telescope cannot be used photographically. In this case, something might still be done by using plates stained with erythosin. Great steadiness of the air, such as seldom occurs at existing Observatories, is requisite for Nos. 1, 4, 11, 12, 13 and 18. For Nos. 3, 6, 9, 10, 14 and 15, the sky must be dark and no electric lights near.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Jan. 11, 1893.

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COMPLIMENTS OF THE AUTHOR.

The Constitution of the Stars.

EDWARD C. PICKERING.

Reprint from ASTRONOMY AND ASTRO-PHYSICS, No. 118.

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THE CONSTITUTION OF THE STARS.*

EDWARD C. PICKERING.

Our only knowledge of the constitution of the stars is derived from a study of their spectra. This has been done at the Harvard College Observatory as a portion of the work of the Henry Draper Memorial. Photographs have been taken of the spectra of the brighter stars on a large scale, some of them being as much as six inches in length. To photograph the fainter stars, a smaller dispersion is employed and in this way the spectra of stars as faint as the ninth or even the tenth magnitude may be obtained. To study the stars too far south to be visible in Cambridge, expeditions have been sent to South America, and a permanent observing station has been established near Arequipa, Peru, at an altitude of about eight thousand feet. There the southern stars are photographed with instruments similar to those used in Cambridge for the northern stars. A few spectra have been photographed with plates stained with erythrosin, which renders them sensitive to the yellow rays. A portion of the visual spectrum not shown on an ordinary plate is thus photographed. Images of the sodium line "D" in which the two components are clearly visible have been obtained for several stars. In all, many thousand photographs have been collected, including stars in all parts of the sky, from the north to the south pole. The spectra of all the bright stars have been photographed as described above, with a large dispersion, and the spectra of a large portion of the faint stars with a small dispersion. A careful study has been made by Mrs. M. Fleming of the fainter stars, and of the brighter stars by Miss A. C. Maury. From this it appears that while at first sight many spectra seem to be unlike, nearly all of them can be arranged according to a simple system. It is not proposed in the present paper to consider the cause of these differences. For purposes of description, it will be convenient to treat them as if due to differences in composition only, although there is evidence that the actual variation is rather in the order of growth. The spectra of ninety-nine one hundredths of the stars could be imitated by combining in different proportions four sets of lines. These are first, hydrogen; second, a substance presumably calcium in such a condition that it gives the broad lines "H" and "K" which

* Read at the Congress of ASTRONOMY AND ASTRO-PHYSICS, Chicago, August, 1893.

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are the most marked features in photographs of the solar spectrum; thirdly, the substance, or substances, which give the lines characteristic of many of the bright stars in Orion; fourthly, the lines of the solar spectrum omitting those due to hydrogen and calcium. These four classes of lines may be described as hydrogen, calcium, Orion and solar lines. We may now arrange nearly all the visible stars in a sequence such that the spectra change insensibly from each one to the next. At one end of this sequence are such stars as α Virginis, α Eridani, and β Canis Majoris. In them, the Orion lines and hydrogen lines are well marked. The principal Orion lines have wave-lengths 382, 402 and 453, and are sometimes nearly as intense as the hydrogen lines. These spectra are designated by the letter B in the provisional classification adopted in the Draper Catalogue. In the next stars of the sequence the Orion lines have become fainter and the hydrogen lines stronger while the calcium and solar lines are faintly seen. This gives the large class of stars called A in the Draper Catalogue, of which the Milky Way is mainly formed. The stars α Canis Majoris and α Lyræ are examples of this class. The hydrogen lines here so greatly exceed all the others in intensity that in faint spectra they are the only lines visible. The line "H" due to hydrogen has a slightly greater wave-length than the corresponding line due to calcium. When these lines are well defined and about equally intense the H line appears double. This is well shown in such stars as α Cygni in which the hydrogen lines are narrow, but is also distinctly seen in good spectra of α Lyræ and other normal first type stars. In some stars such as α Aquilæ the hydrogen and other lines are broad and ill defined as if the spectra were out of focus. It is possible that this is due to a rapid revolution of the stars around their axes by which the portion near one edge would be receding while that near the opposite edge is approaching. But the velocity required, about a hundred miles a second in the case of α Aquilæ, is so great that such a hypothesis must be accepted with caution. The calcium and solar lines now gradually increase, and the Orion lines diminish in intensity, until they disappear; the hydrogen lines "G" and "h" also diminish. This class of spectrum is called F in the Draper Catalogue. The K line is as intense as the H line and the h and G lines are distinctly fainter. The stars α Argus (Canopus) and β Cassiopeiæ are examples of this class. The solar lines now steadily increase in intensity and the hydrogen lines diminish until the latter are no more intense than some of the solar lines. The typical second type stars are here reached and are represented by α Auri-

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gæ, α Centauri, and α Ursæ Minoris. They are called G in the Draper Catalogue or E if so faint that only the principal lines are visible. Before reaching this point we may have the hydrogen and solar systems of lines both strong as in α Canis Minoris. It is therefore difficult to decide whether both substances are combined in a single star, or whether the star is a close double, one component having a spectrum of the first, the other of the second type. This combination often occurs in double stars. In fact it has long been noticed that in the case of double stars, the brighter component is frequently of a reddish, the fainter of a bluish tint. The spectrum of the first star is then often of the second, while that of that of the second star is of the first type.

The photographs of the prismatic spectra so far described have a uniform density from the F to the H lines, that is from wave-length 397 to 486. As we progress in the series the density of the portion of the spectrum of greater wave-length increases as compared with the other portion. With sufficient dispersion the spectrum is seen to undergo a sudden diminution in density as the wave-length diminishes at the point whose wave-length is 430. The difference in brightness becomes more marked, as the dispersion diminishes, so that when the dispersion is small very faint stars of this class may be recognized by their short spectra, the portion whose wave-length is less than 430 not being visible. Probably the classification of spectra may be carried to fainter stars by means of this property than by any other. The letters H, I, and K are used in the Draper Catalogue to designate such stars. Their spectra may be regarded as forming a second division of the second type. The Sun and α Boötis are striking examples of this class, and α Tauri is a star still further advanced in the series. As we progress in the sequence a second sudden change in intensity takes place at the point whose wave-length is 476. Unlike the other change the intensity of the portion of shorter wave-length here exceeds that of greater wave-length. This may be regarded as the distinctive feature of the photographic spectra of stars of the third type. The brighest star of thisclass is α Orionis. The letter M is used to designate spectra of the third type in the Draper Catalogue. These stars may be further subdivided into four classes, of which the first is that just described. The second is represented by α Herculis in which the spectrum is distinctly banded, each band having its edge of greater wave-length bright. The third class is not represented by any bright star. Many of the variable stars of long period have this spectrum when they are not near their maxima. Variable

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stars of long period, when near maxima, constitute the fourth division which differs from the third only in having one or more of the hydrogen lines bright.

Two classes of spectra must now be considered which are not provided for in the above classification. The first of these consists of the spectra of gaseous nebulæ, the second, that of the stars whose spectra consist mainly of bright lines. The wave-lengths of the lines in both of these classes of spectra appear to coincide with those of the Orion and hydrogen lines. They therefore appear to precede the Orion stars in the sequence described above, but the lines are bright instead of dark. While an ordinary star may be regarded as having a bright nucleus giving a continuous spectrum surrounded by an absorbing medium, the bright nucleus in these objects is wanting, and the spectrum appears to be directly due to the incandescent gas. The reversal in brightness may thus be explained. The gaseous nebulæ can be divided into at least two classes and the bright-line stars into at least three. A few other stars have one or more bright lines in their spectra; for instance, such stars as γ Cassiopeiæ, and φ Persei in which the F line is bright. They generally belong to the Orion class, and probably so much hydrogen is present in their atmospheres that the absorption is overbalanced by the direct light of the gases.

One other class of spectra remains, that of stars of the fourth type. Their spectra appear to be identical with that of carbon. Almost sixty of these objects are known. They are intensely red and therefore difficult to study photographically. No connection has as yet been established between them and the sequence of spectra described above.

A few peculiar stars like Nova Aurigæ remain, but their number is so small, that for the present each may be considered by itself.

The classification of the stars according to their spectra is so far-reaching that it should be applied to each of their other properties. For instance, of the variable stars it appears that all known Algol stars have spectra of the first type, while long period variables in general are of the third type, and have the hydrogen lines bright when near their maxima, as stated above. This property has led to the discovery of more than twenty objects of this class, and no exception has been found of a star having this spectrum whose light does not really vary. Of the variables of long period which have been discovered visually, the hydrogen lines have been photographed as bright in forty-one, the greater portion of the others being too faint or too red to be

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studied with our present means. A few variable stars like U Hydræ, R Sculptoris, and B.D. + 62° 596 are of the fourth type. Their variation is small and their red color renders their visual observation uncertain. Variable stars of short period generally have spectra of the second type, but some like β Lyræ present special peculiarities.

The motion of the Sun in space, as derived from stars of each class of spectrum, is a problem of especial importance. The plan of the Henry Draper Memorial provides for the study of each of these and similar problems.

In general, it may be stated that with a few exceptions, all the stars may be arranged in a sequence, beginning with the planetary nebulæ, passing through the bright-line stars to the Orion stars, thence to the first type stars and by insensible changes to the second and third type stars. The evidence that the same plan governs the construction of all parts of the visible Universe is thus conclusive.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., August 5, 1893.

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FORTY-EIGHTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING OCTOBER 31, 1893.

BY

EDWARD C. PICKERING.

CAMBRIDGE, MASS.
PUBLISHED BY THE UNIVERSITY.
1893.

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REPORT.

To the President of the University:

Sir, — The most important event to be mentioned in the present report is the completion of the new fire-proof brick building, and the transfer to it of about 30,000 stellar photographs. The second expedition to our Peruvian observing station has returned, and the third expedition has begun work successfully. The entire income of the Paine Fund, one of the largest gifts ever made to astronomy, is this year for the first time available for the use of the Observatory. Notwithstanding this important increase in our resources, the expenses due to additional work undertaken have also become greater, so that no new researches can be begun for the present. The addition to the Paine Fund will, however, compensate for the loss that this Observatory, like other American observatories, has suffered by the action of the U. S. Naval Observatory in depriving them of income from the sale of time signals. The expense of the second Peruvian expedition proved much greater than was anticipated, and has caused a considerable deficit in the Boyden Fund. The expenses for publication which are to be paid from the unrestricted portions of the income of the Observatory are likely to be large in coming years, and if possible a portion of the income should be reserved for a building fund, which will soon be required if the Observatory maintains its present rate of growth. The Observatory was represented at the Chicago Exhibition by a collection of about 250 photographs, and portraits of Bond, Paine, Boyden, and Draper.

Observatory Instruments.

East Equatorial. — The systematic observation of variable stars upon the system described in the last report continues to be the principal work of this instrument; but the photometric observation of the eclipses of Jupiter's satellites and the observation of comets are also carried on as before. The observer was Mr. O. C. Wendell, except that 9 of the 25 eclipses of Jupiter's satellites, photometric measurements of which were obtained during the year, were observed by the Director. The wedge photometer was used in 48 series of observations, comprising 3354 measurements, for determining the brightness of 1118 stars occurring in the Durchmusterung. Comet 1892 III. was observed 21 times for position, and was photometri-

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cally measured on 13 nights. Comet 1893 I. was observed 3 times, and Comet 1893 b 11 times, for position; the last was photometrically measured on 3 nights. One observation of the position of Comet 1893 c was also made. About 4000 measurements were made with the polarizing photometer, including (1) determinations of the relative light of the components of 65 of the brighter double stars, (2) determinations of the brightness of variable stars, including the new star in Auriga, which was observed on 8 nights, and (3) determinations of the brightness of faint comparison stars near circumpolar variables. The selection of these stars and the measurement of their positions also formed part of the work. Comparison stars selected from the Durchmusterung for a series of 60 variables have now been revised; one third of this work was done during the past year. Over 200 relative and as many absolute estimates of the brightness of variable stars were obtained, principally when they were faint; also 35 relative and as many absolute estimates of the brightness of the new star in Auriga. Some miscellaneous observations were likewise made.

Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision. The catalogue of the zone between the declinations $+49°\ 50'$ and $+55°\ 10'$ has been published and distributed, forming Volume XV., Part II., of the Annals of the Observatory. Volume XXV., containing the comparison of the positions in this catalogue with those of the same stars in previous catalogues, the resulting proper motions, and the comparison of the separate observations of each star with each other, has also been published. The printing of the journal of the zones is to be undertaken at once.

The reduction of the observations of the southern zone between the declinations $-9°\ 50'$ and $-14°\ 10'$ has been continued through the year. The work is complete with respect to the fundamental stars, except so far as it may be affected by the publication of their final places derived from observations elsewhere. Much work has also been done in reducing the observations of the zone stars. Observations of β Persei and the comparison stars proposed for it by Dr. Chandler were made on 10 nights, and the results were published in Volume XXIX. of the Annals of the Observatory.

Meridian Photometer. — Good progress has been made in the reduction of the photometric observations of the southern stars made in Peru by Professor S. I. Bailey. A portion of the catalogue is in type and the remainder is ready for the printer. Observations have

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been made by the Director with the meridian photometer on nearly every clear evening during the past year. The number of series is 107, and of separate photometric comparisons 46.272. The observations ordinarily last from seven to eleven in the evening; but last summer they were extended to one or two o'clock in the morning in order to complete the observation of the large number of stars in the Milky Way which can only be observed at that season. The observing list contains about 6000 stars, including the 4000 contained in the Harvard Photometry, which are thus reobserved. About three quarters of the observations required to complete this list, each star being observed on at least 3 nights, have now been made.

West Equatorial. — Mr. W. M. Reed made observations with this instrument on 87 evenings; these observations include 489 on variable stars, 1318 on comparison stars (among which are 178 made with the prismatic photometer mentioned in former reports), and 10 on the brightness of the comet discovered by Holmes. Meteors were seen passing through the field of the telescope on 25 occasions, and a record has been kept for 2 years of these phenomena, stating their place, movement, color, and other circumstances connected with them. 9 observations of aurora seen at Cambridge were made on 8 evenings.

Henry Draper Memorial.

The number of objects having peculiar spectra, which are annually discovered by Mrs. Fleming in her examination of the Draper photographs, has not diminished. The most important of these objects is a new star in the constellation Norma, whose spectrum was photographed at the Arequipa station on July 10, 1893, and of which no trace was visible on 13 plates taken from June 6, 1889, to June 21, 1893. Its spectrum appears to be identical with that of the new star which appeared in Auriga in December, 1891. 7 variable stars, T. Cassiopeiae, S Geminorum, T Geminorum, S Virginis, V Bootis, R Piscis Austrini, and S Aquarii, in addition to the 47 previously announced, have the hydrogen lines bright in their photographic spectra. 3 new variables have been discovered this year by means of this property. The number of stars of the fifth type has been increased by 10, making the total number now known of these objects 55. The hydrogen line F has been discovered to be bright in the spectra of BD. — 13° 893, magn. 5.8, and — 10° 1786, magn. 7.3. 10 stars have been shown to have spectra of the fourth type.

All of the spectrum plates have been carefully examined for the detection of objects of interest. The spectra of 20,149 stars on

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190 plates having 60 minutes exposure have been classified for a revision and extension of the Draper Catalogue to include fainter stars and cover the entire sky. The number of photographs taken with the 8 inch Draper telescope is 2424; with the 11 inch, 1037. The latter include 213 photographic images of the spectrum of β Aurigae, 145 showing the principal lines double. The lines are double in 4 of the 94 photographs of ζ Ursae Majoris.

Boyden Department.

The second Peruvian expedition, under the direction of Professor W. H. Pickering, returned to Cambridge last spring after successfully observing the Total Eclipse of the Sun on April 16, 1893. Surveys were made which determined the positions and altitudes of various points in the Sorata range in Bolivia, and of Mt. Aconcagua in Chile. The most important astronomical work undertaken was the study of the members of the solar system by means of the 13 inch Boyden telescope. This included a study of the lunar rills and of variable spots upon the Moon and catalogues of them; of the diameters of the satellites of Jupiter, of their elongated shapes, the inclination of their axes of form, their axes of rotation, their markings, and the determination of the retrograde rotation of the first satellite; also a study of the markings of the planet Neptune. A series of measurements was also made of the double star α Centauri. These observations confirm the conclusion that the atmospheric conditions at Arequipa are particularly favorable for astronomical observations. It is extremely important that we should avail ourselves of the opportunities thus afforded by erecting at this station a telescope of the largest size. If this cannot be done, a telescope of 20 or 25 inches aperture would add greatly to our present knowledge of the surfaces of the planets and of other objects for which great magnifying powers are required. It is hoped that this matter will be borne in mind by those who wish by their gifts to advance astronomical science. The number of photographs taken with the 8 inch telescope was 250; with the 13 inch, 112. These numbers would be greater but that the cloudy season is included in the portion of the year here under consideration.

The third expedition, under the direction of Professor Solon I. Bailey, began work on April 4, 1893. Since then 1516 photographs have been taken with the 8 inch telescope and 852 with the 13 inch telescope. An eyepiece has been attached to the latter instrument so that the motion of the telescope may be controlled by an image formed by its own objective, thus dispensing with a finder. Very remarkable

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photographs have thus been obtained of the principal southern clusters. On a photograph of ω Centauri over 7000 stars were counted by Professor Bailey in a region 30′ square. 2 of these stars have been found to be variable, 1 being discovered by Mrs. Fleming, the other by the Director. Professor Bailey has shown that 3 stars are variable in the cluster 47 Tucanae. The images of the stars in these clusters are almost perfectly circular, although the exposure in some cases exceeded 3 hours. 104 photographs have been obtained with the 2½ inch Voigtländer doublet. The brightness of about one half of the stars south of declination —30, and brighter than the magnitude 6.3, has been determined visually.

Until recently the highest meteorological station in the world has been that established by this Observatory on Mt. Chachani at an elevation of 16,650 feet, After making a careful examination of the volcano El Misti, Professor Bailey has succeded in establishing a station upon its top at an elevation of 19,200 feet. A path has been constructed by which mules have been led to the summit, and beside the meteorological shelter a wooden hut has been built upon the summit. A survey of the craters has been made, and a stone hut has been erected on the side of the mountain at a height of 15,600 feet. The temperature, pressure, moisture, and the velocity and direction of the wind are now being recorded at the summit station by self registering instruments. The sheets are changed at intervals, thus giving a record of atmospheric conditions at a height hitherto unattempted. The use of beasts of burden at these heights offers an opportunity in the future of carrying instruments and conducting experiments at altitudes heretofore regarded as inaccessible for these purposes. The mountain as seen from every direction is an isolated sharp peak. It is therefore especially suited for the study of the upper atmosphere.

The Bruce Photographic Telescope.

This instrument is now nearly completed, and photographs will be taken with it in a few days. So far as can be judged at present it seems likely to accomplish all that has been expected of it. The brick building with sliding roof to contain this instrument is finished and a large part of the mounting is in place.

Photographs have been taken with the Bruce transit photometer on 154 evenings, and when clear, throughout the entire night. A large part of them have been identified so that they will be immediately available, if required as in the case of the new star in Auriga. Good progress has also been made with the measurement of the forty thousand stars of the tenth magnitude which are being selected for standards for faint stellar magnitudes.

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Misscellaneous.

Zodiacal Phenomena. — An effort has been made to obtain observations as nearly contemporaneous as practicable, and made at widely separated points, of the distribution of light in the zodiac, and particularly of the slight maximum of light nearly opposite the Sun, known as Gegenschein or Counterglow. Professor Barnard, of the Lick Observatory, kindly undertook to coöperate in this work, as did also Professor Bailey at Arequipa. Accordingly, during moonless nights in September, 1893, 36 observations were obtained; 13 of them by Professor Barnard, 3 by Professor Bailey and 20 by Professor Searle and Mr. Reed at Strafford, Vermont. Mr. A. E. Douglass also made some observations at Cambridge, notwithstanding the interference of the number of electric lights in this vicinity. The corresponding numbers of observat ons in October were 9, 3, and 35; the last were made by Messrs. Douglass and Reed, largely at Blue Hill, but partly at Cambridge and elsewhere. The conclusion of most immediate interest is that resulting from the comparison of the positions of the maxima of light observed at the different stations. In these no effect of parallax can be discerned.

Library. — The library of the Observatory has been increased during the year by the addition of 294 volumes and 715 pamphlets. The total numbers of volumes and pamphlets on November 1, 1893 were 4492 and 9460 respectively.

As the station at Arequipa, Peru, will be maintained permanently, it is desirable, owing to its remoteness, that it should have a library of its own. Copies of astronomical and meteorological works sent thither direct, or through this Observatory, will be gratefully received and will prove of much value.

Telegraphic Announcements. — The distribution of telegraphic announcements of discovery has been continued as in past years. although Mr. Ritchie has resigned his position as Assistant in the Observatory. Astronomers are requested to continue to send to this Observatory announcements of their discoveries for transmission to the observatories of Europe and America.

Buildings and Grounds. — On March 2, 1893, a transfer was made of a large portion of the contents of the west wing of the main building of the Observatory to the new brick building. Nearly thirty thousand glass photographic plates were transferred from one building to the other without serious accident. The greater number of

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the plates measured eight by ten inches, and the total weight of the glass was about eight tons. A rope was stretched from the old building to the new, and boxes each containing one hundred plates were attached to a pulley and allowed to run down. They were thus transferred at the rate of about six thousand an hour. Apart from the importance of protecting the photographs from injury, the new building proves of the greatest convenience in providing additional room for their examination, and for the corps of computers engaged in their study. The alterations in the residence made by the Director have been completed, and afford much additional space for the accommodation and entertainment of visiting astronomers.

Certain observations at Cambridge are each year rendered more difficult. The introduction of electric lights, especially in the vicinity of the Observatory, greatly interferes with the observation of faint objects. Additional trouble is anticipated from the proposed introduction of electric cars on Concord Avenue, which forms the southern boundary of the grounds of the Observatory. A more serious difficulty is apprehended from the proposed widening of Concord Avenue, which, if carried out, would bring the cars still nearer the instruments, and would necessitate cutting down the row of large spruce trees by which the instruments are now partially protected from the dust of the road. The citizens of Cambridge and the friends of the Observatory should be alike interested in saving this fine collection of trees from destruction.

Publications. — The following volumes in the series of Annals of the Observatory, some of which were mentioned last year as nearly complete, have been published and distributed: XV., Part II., XIX., Part II., XXV., XXIX., XXX., Part III., XXXI., Parts I. and II., and XL., Part I. Volume XL., Part II., has also been published and distributed. It contains the Blue Hill Meteorological Observations for 1892. The series of volumes is now complete to Volume XXII. inclusive. Volumes XXIII., Part II., XXVI., Part II., and XXVIII. are not yet undertaken. Volume XXIX., above mentioned as published, was completed by the addition of articles on the magnitude of bright stars north of $+70°$, and on meridian circle observations of β Persei. Volume XXX., Part IV., is not yet published. Volume XXXIV. has been begun and 112 pages are in type. It contains the results of the observations of the brightness of the southern stars made with the meridian photometer by Professor Bailey. Volume XLI. has also been begun, and 19 pages are in type. It will contain annual summaries of observations made by the New England Weather Service, to which the similar work of the New England Meteorological Society has been transferred. The summary

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for 1892 is almost completed. Thirty-two pages of meteorological observations made in Peru have also been printed. They have not yet been assigned to a volume.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-seventh Annual Report of the Director of the Astronomical Observatory of Harvard College. Cambridge, 1892.

A Large Southern Telescope. Circular issued last year and reprinted in Astronomy and Astro-Physics, xi. 783.

Publications and Photographic Illustrations issued by the Observatory of Harvard College. Cambridge, 1893.

The Astronomical Observatory of Harvard College. Circular describing the stations, instruments, and publications of the Observatory. Cambridge, 1893.

Improved Methods of Observing the Zodiacal Light. By Arthur Searle. Astronomische Nachrichten, cxxxii. 163.

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EDWARD C. PICKERING, *Director*.

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Telescope Mountings and Domes.

WILLIAM H. PICKERING.

Reprint from ASTRONOMY AND ASTRO-PHYSICS.

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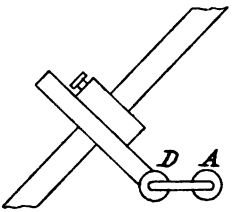

Fig. 1

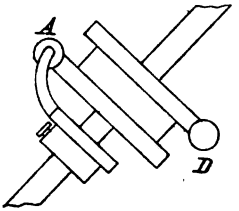

Fig. 2

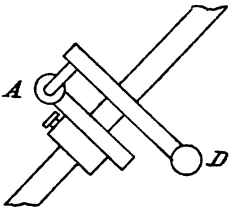

Fig. 3

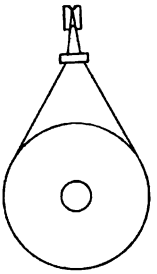

Fig. 4

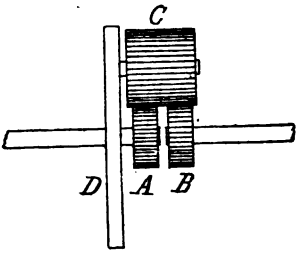

Fig. 5

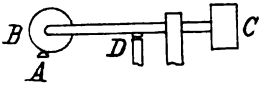

Fig. 6

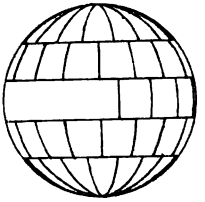

Fig. 7

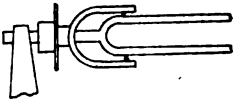

Fig. 8

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TELESCOPE MOUNTINGS AND DOMES.*

WILLIAM H. PICKERING.

A recent brief visit to Europe has enabled me to make a study of a number of different telescope mountings in use in England and France, and to compare them with some of those employed in our own country. An especial study has been made of the arrangements for following a star in the telescope, and keeping it exactly upon the cross hairs. This is a matter of comparatively little consequence for visual work, but for photography it is one of vital importance, since owing to variations in the refraction with the altitude of the star, the driving clock can never follow with perfect accuracy, no matter how accurately the clock itself may run.

By far the most common method of following is by means of a slow motion screw adjusted by hand. This works in a nut in most of the American telescopes, while in the foreign instruments it usually fits into a worm wheel or sector similar to that actuated by the driving screw. In the Clark mounting, Figure 1, the driving screw D is attached to a nut working on the slow motion screw A, both being seen endwise. By turning the slow motion screw the driving screw is moved bodily forwards or backwards, thus turning the worm gear which is clamped to the polar axle. In the Warner & Swasey mounting which is somewhat similar in construction to that represented in Figure 3, the driving screw turns a worm gear which is loose on the polar axis. This worm gear carries the slow motion screw which fits into a nut attached to an arm which is clamped upon the polar axle. In the French method, Figure 2, as made by Gautier, there are two worm gears exactly alike, cut upon the same wheel, which turns loosely upon the polar axle. The slow motion screw A is clamped to the axle and is carried by the loose wheel, which is driven by the driving screw D. In the English mounting as

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made by Grubb, Figure 3, the slow motion screw is attached to the loose wheel, and this screw turns a second worm gear which is clamped to the polar axle. Grubb usually employs sectors instead of complete wheels, as do also the other makers very frequently.

For photographic work the complete wheel for both driving screw and slow motion has a decided advantage over the sector, as the latter rarely permits of exposures of much longer than two hours' duration. Where several short exposures are to be made in one evening it is a great inconvenience to be constantly obliged to set back the sector, or else to have to consider whether it is likely to run out before the exposure is over. The only advantage of the sector is that it allows a greater radius to the worm gear than does the wheel, but if the gearing of the wheel is carefully ground, no appreciable irregularity in the motion will be introduced by this cause. While both of the European methods employ an extra worm gear for the slow motion they have the corresponding advantage where a complete wheel is used that neither of the screws ever come to an end, but may be turned indefinitely. It seems to me therefore that a complete worm gear for each screw is most desirable, and that here if we use a slow motion screw at all, we cannot do better than follow the European example.

The method of turning the slow motion screw is usually either by a double Hooke's joint, or by a cord passing over a large wooden wheel. In the latter case the cord may be conveniently made to embrace the wheel by passing it through a small but heavy ring which hangs freely upon the cord by its own weight, Figure 4, and thence over a horizontal axis.* The Henry brothers use the Hooke's joint, with a long handle capable of reaching the hand when the observer is looking through the finder. We have employed the same method at Harvard, but have found it inconvenient and rather unsatisfactory. For very large telescopes it is almost out of the question. Besides the cord, and the Hooke's joint, there is a third method of turning the slow motion screw, employed first by Repsold. This is the method of ring gears, in which the screw is connected directly by a system of mitre gears turning upon the polar and declination axles with a long handle running down the side of the telescope tube. Thus the declination and the right ascension adjustments are made by turning two handles placed side by side. This is a very convenient arrangement, but there is a certain amount of

* This arrangement is used in Dr. Huggins' Observatory.

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back lash introduced by this adjustment, and for large instruments the ring gears are necessarily very heavy. Still another method of turning the slow motion screw which has occurred to me is to connect it through suitable gearing with a small electric motor. Wires could then be attached by which the current could be transmitted in either direction through the motor, causing it if properly arranged, to carry the screw either backwards or forwards, at will. This seems in some respects the most completely controlled method of turning the screw in case electric power is at hand.

But there are other methods of correcting the motion in right ascension which dispense with the slow motion screw altogether. One of these, known as the "mouse control," is employed by Grubb on many of his instruments. In Figure 5 let A and B be two gears which are just alike save that one of them has one more tooth than the other. Their respective axles are in line but disconnected. The left hand axle transmits the power, and the right hand one is connected with the driving screw. D is a loose pulley, carrying the loose gear or so-called "mouse," C, which connects the gears A and B. When the power shaft revolves, carrying the pulley D, the driving screw shaft also turns at the same rate. If now we stop D in any position, the differential gearing of A and B comes into play, causing the driving screw to move at a slightly increased or diminished speed as the case may be. D may either be turned backwards or forwards by a cord, increasing or diminishing the rotation of B, or else two separate mouse controls may be employed, one for increasing and the other for diminishing the speed. In the latter case the pulleys are stopped electrically by wires leading directly to the hand.

It seems to me that the "mouse control" is a decided step in advance in the direction of accurate adjustment, over the slow motion screw. In our 13-inch telescope an endwise push of the driving screw of $\frac{1}{6000}$ of an inch moves the photographic plate through 1″. This slight motion of the screw may be entirely masked by the back-lash, or other causes, and in practice we find such is the case, and that accurate following for enlargments is a very difficult matter. The mouse control avoids all this, by simply changing the rate of motion of the driving screw, in the simplest manner imaginable, and no slow motion screw whatever is needed.

There is a very convenient device of general application which is employed at Greenwich, but whose bearing in the present instance does not at first sight appear. When it is wished to

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correct the error of the standard meantime clock, it is not done by adding or removing small weights from a scale pan, as is customary at many observatories. Instead of this there is attached to the front of the pendulum of the clock a verticle permanent bar magnet, measuring 5 × ⅜ × ⅛ inches. Just below the magnet is placed a helix attached to the clock case. It is connected with a battery of eight Leclanché cells, and has no iron core. By passing a current through this helix in one direction or the other the error of the clock can be changed by six seconds, inside of one hour. In talking this matter over with Mr. Douglass afterwards it appeared that this arrangement might be adapted to the control clock of an equatorial. It would probably be best in order to change the rate more rapidly to employ two helices, one above and one below the magnet, and to furnish them with iron cores. By this arrangement no slow motion screw and no "mouse control" would be necessary. An electric current would merely be passed through the helices the intensity and direction of which could be varied by turning a switch held in the hand. Like the "mouse control" this adjustment would never come to an end, and it would have an advantage even over it in one respect. If in following a star we found that it was gradually leaving the crosswires, we should not be obliged to continually bring it back again every few minutes, as soon as we were able to detect an appreciable error in its position. We should do better than that. We should pass a slight current through the coils and change the rate of the clock, so that no error of position should occur,—and this without disturbing the driving mechanism in the slightest degree. It seems to me that we have here a new principle of following,—instead of constantly correcting the error of the clock, as the star varies in altitude, we merely correct the clock rate.

At Greenwich two methods of correcting the equatorial are employed, a rapid one by the slow motion screw, and a slow one by the "mouse control." I should suggest a rapid correction by a quick acting "mouse control" run forwards or backwards by a small electric motor, and a slow correction by the clock, and a rejection of the slow motion screw altogether.

Leaving this subject, let us now turn to the automatic control. This control is of two kinds; first that which is permanently attached to the driving clock, and is in continuous action though at a varying rate, throwing additional work on the clock when it runs too fast, and relieving it when it runs too slowly. The second kind is that which acts intermittently, throwing in addition-

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al work when the driving clock gets ahead of an independent control clock, but never relieving the driving clock of any of its own work. In the Grubb and Warner & Swasey mountings the continuous control is accomplished by means of a ball governor, which, when the balls fly out, increase the pressure and therefore the friction, upon a fixed smooth metallic surface. In the Clark mounting the continuous control consists of a rapidly revolving fan wheel, whose vanes are set at a fixed angle before starting the clock. In the Gautier mounting invented by Foucault, the balls of the ball governor are each set in the center of a fan, so that when the speed is increased the fans fly out, and a very large increase of atmospheric resistance ensues, which regulates the rate of the clock in a surprisingly perfect manner. This form of control has been employed upon some American chronographs. So perfect, indeed, in action is it when carefully made, that Gautier does not consider it necessary to employ any additional intermittent control, or any pendulum whatever about the telescope. Nevertheless the astronomers who have used it tell me that while the clock follows admirably for short exposures such as five minutes, as indeed I was able to prove to my own satisfaction, yet when the exposure is longer, slight corrections were constantly necessary. These deviations may of course have been produced by refraction, but the observers themselves seemed to think that the introduction of a pendulum into the mechanism would be an improvement. The Foucault adjustable vanes are it seems to me an improvement on the fixed vane system, and I am inclined to think would be more uniform in their action than any control depending on the friction of solid bodies. In connection with a "mouse control" this device seems to me admirably adapted to telescopes intended solely for visual purposes.

Regarding the intermittent control introduced by an external and independent clock, Gautier, as we have seen, employs none. Grubb again introduces mechanical friction, but in the Greenwich instrument substitutes as omewhat complicated form of "mouse control," while Clark permits a spiral spring to be wound up to a greater or less extent, which when electrically released at the end of each second delivers its absorbed energy in the form of a blow, which does not affect the speed of the driving mechanism. When the parts affected are made strong enough to withstand the repeated blows, the latter method gives very excellent results.

Regarding the electrical connections, I found little to be learned in Europe. The Greenwich method of closing the circuit was to let the end of the pendulum swing through a drop of mercury. This

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method enjoys the advantage of simplicity, but in our own case we found that the mercury had constantly to be renewed, at some inconvenience, and that even then the action was not always certain. A second arrangement that we tried consisted of a pin inserted on the face of the pendulum rod, near the top, which at each swing of the pendulum lifted a light spring furnished with a platinum contact. This is a well known method, but we found that unless the clock is a strong one, it is liable to stop it. We next tried attaching a small permanent horseshoe maget to the face of the pendulum, and allowed it to swing over an armature attached to a spring. This device is also an old one but was described anew a few years ago in the *Sidereal Messenger* by Mr. Gerrish. It works pretty well, but though there is no friction introduced whatever, there is a much larger amount of energy absorbed in the magnetic induction than one would at first sight by any means suppose. The next apparatus for the purpose that we tried was made for us by a Peruvian watch-maker, and is represented in Figure 6. A pin A attached to the pendulum lifts a little lever BC by passing under the loose wheel B. This breaks the circuit at D. This contact is easily reached and cleaned without disturbing the pendulum, and the apparatus furnishes on the whole the best make and break that we have yet found.

In bringing this article to a close I will take advantage of this opportunity to make a few suggestions that have occurred to me as a result of my investigations. They are particularly adapted to the mounting of a large telescope, but some of them may perhaps be of use in the case of a smaller instrument. It seems to me that the cheapest and lightest form of building that could be erected to cover a large telescope would be built upon the plan of a large railway depot. In Figure 7 which is a plan of the dome, a steel ring is first laid to form its base. On this a series of parallel steel arches are erected of suitable sizes. These are united and braced by a series of cross ties giving the structure its final form. For small domes wood could be used as a substitute for steel. The whole is then either covered with sheet metal, or perhaps better still with galvanized iron netting. Finally the netting is covered with water proofed canvas. It has been found at Greenwich that netting covered with papiermaché stands the climate very well, and we have found in Cambridge that the same is true of canvas stretched upon wood. It therefore seems that a covering such as is here suggested might withstand very well even the rigors of a northern climate. The shutters of the dome

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should slide horizontally according to the Hough or Warner, Swasey plans. The dome should be mounted upon a cylindrical iron framework, covered with one thickness of sheet iron. It is almost universal in Europe to mount the domes upon a heavy base of masonry, which collects and retains the heat well into the night. This principle seems to me to be radically wrong. We have gone to the opposite extreme at Harvard, the buildings, supporting the later domes consisting of a light wooden framework covered with a single layer of thin sheathing. Our experience there and particularly at Arequipa I think fully justifies our method of reasoning.

Permanently attached to the side of the dome, opposite the shutter, should be placed the curved rails on which the chair is to be raised and lowered. The chair, so-called, is a large structure, more nearly comparable to a small room, or perhaps better still to a theatre box. It is furnished with an invalid's reclining rolling chair with book rack attached for making observations near the zenith, with several ordinary chairs, a case of drawers for eyepieces, etc., a table and book shelves for a recorder, mean and sidereal clock dials controlled electrically, and with suitable sounders which can be thrown into the circuit when desired. The motions of the dome, shutter, and chair, which latter is partly counterbalanced by weights moving upon the opposite portion of the dome, are all necessarily moved by an electric-motor, which may be controlled from the chair. The telescope would be clamped in right ascension by the pressure between an electromagnet and its armature. The clamp could thus be instantaneously applied.

The telescope itself is not run by clock-work, but by a small motor. Since even a large telescope can be so balanced as to be readily moved with one hand, it is evident that only a very small motor would be required for this work, one for instance such as might be employed to run an ordinary sewing machine. Such a motor would hardly need a separate pier from the telescope, but if found best one could be provided for it. The speed of the motor would be regulated by a tuning fork commutator, which would be more than sufficiently uniform for the purpose, (Figure 8). The rate of vibration would be regulated by jaws pressing upon the prongs of the fork near the crotch, and the length of the prongs thus regulated by a micrometer screw. The tuning fork would be placed in the chair beside the observer, who could allow for the varying refraction of the star he was observing by a touch of the screw. This plan would have all the advantages of

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the pendulum control above described, since the observer would change the rate, and not the error, of his driving mechanism. In short the motor would save expense, save space and save winding. There would be no slow motion screw, no pendulum, no revolving fans, no ball governor. Yet it seems as if it would give quite as good results as the driving clock, besides being far more easily and conveniently controlled.

HARVARD COLLEGE OBSERVATORY,
December 1, 1893.

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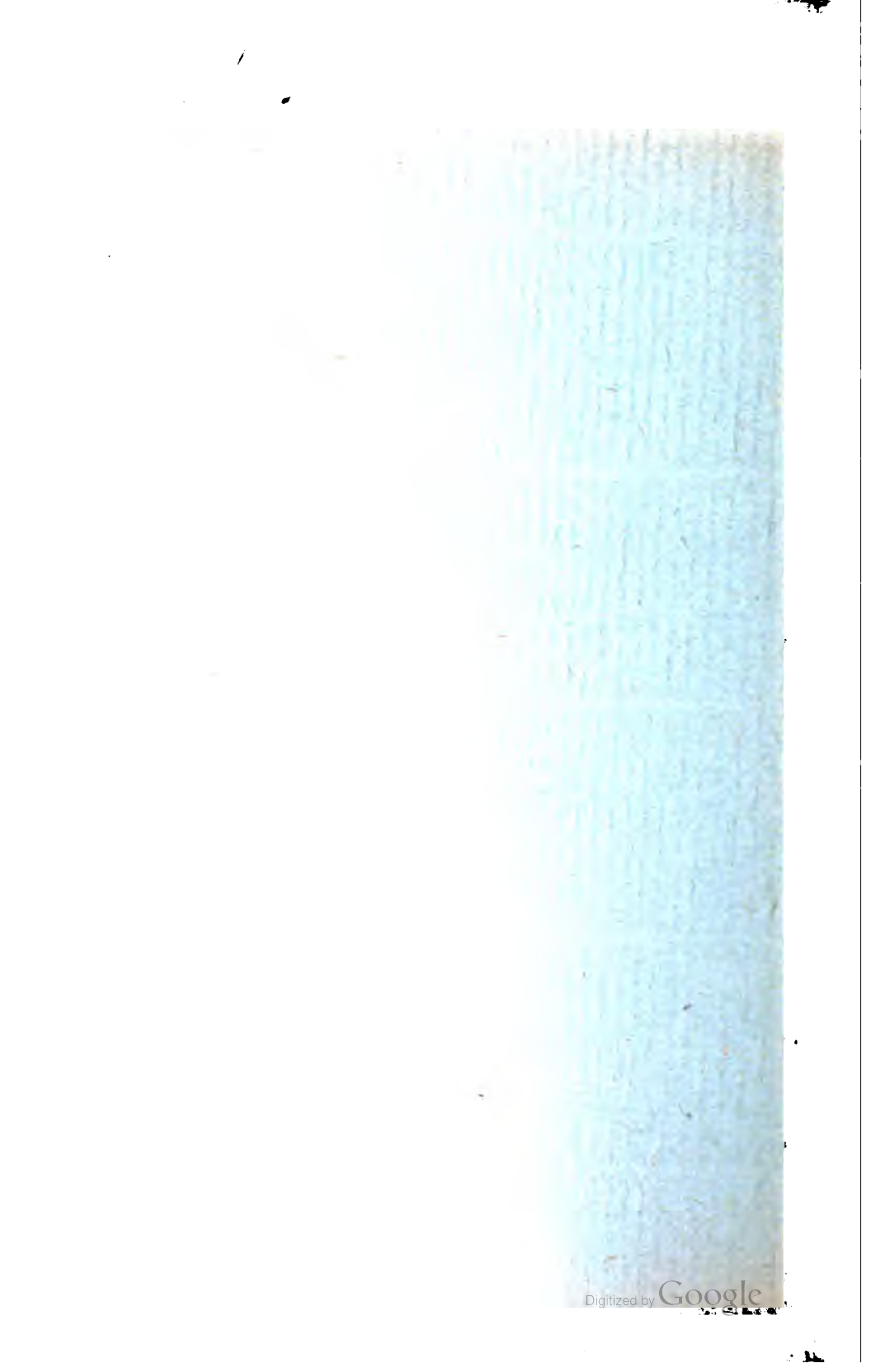
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A Study of Nova Aurigæ and Nova Normæ.

WILLIAM H. PICKERING.

Reprint from ASTRONOMY AND ASTRO-PHYSICS.

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A STUDY OF NOVA AURIGÆ AND NOVA NORMÆ.*

WILLIAM H. PICKERING.

Considering that there are but about a dozen well authenticated instances of the appearance of new stars, in the history of astronomy, it is an interesting fact that the last two should have appeared within two years of one another, and that our earliest record of their existence should in each case be due to photography. This fact taken in connection with the other, that a large proportion of the new stars have appeared within recent times, makes it evident that these phenomena are not of such great rarity in nature as was formerly supposed.

Unfortunately our only record of the spectrum of Nova Normæ consists of a single plate. This was taken in the Bache telescope at Arequipa with small dispersion, the total distance from F to H being but a few millimeters. With such a dispersion it is impossible to determine much more than the general characteristics of the spectrum. A comparison has been made with the spectrum of Nova Aurigæ taken under similar circumstances (see ASTRONOMY AND ASTRO-PHYSICS for January, Plate IV). It is found that each prominent bright line in Nova Aurigæ has a corresponding bright line in Nova Normæ, and an examination of the negatives shows that each bright hydrogen line has an accompanying dark one by its side, in both spectra. It both cases the dark line is toward the more refrangible end of the spectrum. It is impossible to determine the relative velocities of the bodies producing the bright and dark lines from these spectra, but it is evident that they are not very different in the two cases.

Turning now to theoretical considerations, the relative velocity of the components of Nova Aurigæ, although high, cannot be considered as very remarkable, being less than three times as great as is frequently found in that comparatively quiescent body, the Sun. Moreover it is less than twice as great as the velocity which would be produced by a body falling from an infinite distance and just grazing the solar surface. But the high velocity in the case of the Nova had evidently no connection with the mutual attraction of the bodies, since it persisted with but slight diminution for several weeks, the two bodies, according to the generally accepted theory, traversing in the meantime a dis-

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tance equal to several thousand times the diameter of the Sun. The very fact that so little change of velocity was detected, would indicate that the combined mass of the bodies must have been comparatively small.

The high relative velocity of the components must then have been due either to a very high initial velocity in both bodies, or to an outburst of some sort, which produced a velocity not much higher than we ordinarily find in the Sun. Let us compare now these two hypotheses. The former is the one almost universally adopted, but the latter I think should not be discarded without some further consideration.

On the hypothesis of high initial velocities, it is generally considered that the two bodies are moving nearly in the line of sight, and that Nova Aurigæ for this reason furnished unusually favorable conditions for our investigation of its nature. But apparently Nova Normæ furnished equally favorable conditions, although unfortunately little advantage was taken of them, owing to our not knowing in time of its existence. The probability is about one in one hundred and twenty that in both instances the line of relative motion should be inclined less than thirty degrees to the line of sight, and that the star giving bright lines should in both cases be going the same way. If we merely require that the line of motion should lie within sixty degrees of the line of sight, the probability that the two spectra should be silmilar is increased to one in eight, but we must admit a maximum actual velocity of the two stars twice as great as that which has been observed by the spectroscope. Moreover, bright line stars are rather rare, and even if we assume that the bright lines were produced by the collision, it is rather singular that in both cases one star only should be so affected. The probabilities, as far as they go, are therefore unfavorable to the correctness of this hypothesis.

Again, how are we to account for the successive reappearances of Nova Aurigæ? Since the relative motion is not due to gravitation, the two bodies must still be receding from one another. It is not probable that each reappearance should be due to a fresh collision with a new and previously unknown body.

It is much easier to attack a hypothesis than to frame a new one, but let us imagine a rather dark Sun, with a viscous surface and gaseous interior. After many centuries of quiescence and contraction a series of eruptive prominences upon an enormous scale burst forth, spreading in every direction, and completely enveloping the star upon all sides. When they first appear, they

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present a spectrum of bright lines, but in a few hours the gases first emitted have receded to a considerable distance from the star, and have cooled down owing to the rapid expansion involved by their recession, which causes them to fill a very much larger sphere than that originally occupied by them. Thus the star very soon becomes enveloped in an atmosphere whose outer regions are comparatively cool. The velocity of the emitted gases is so great, however, that they do not fall back at once, as in the case of the Sun, but continue to recede from the star in all directions. In the case of Nova Aurigæ this motion was at the rate of about 25,000,000 miles a day.

This cold advancing atmosphere produces a series of dark absorption lines. It at the same time cuts off the light from the hot advancing prominences behind it, although a faint reversal of the dark lines in Nova Aurigæ was for a time detected. The hot receding prominences, however, extending away for perhaps millions of miles behind the limb of the star give out a light whose wave-length cannot be absorbed by the cold advancing atmosphere. They therefore shine with their full brilliancy. The phenomenon may last for several weeks or months until the internal pressure is relieved.

Assuming the maximum total relative velocity indicated by the spectroscope to be 800 miles, the velocity involved in the irruptions upon this hypothesis does not exceed 400 miles per second. A solar irruption is mentioned by Young whose velocity equalled 300 miles per second, and prominences are mentioned by him whose altitude reached 400,000 miles. The reversal of the bright lines in the spectrum of the *Nova* would seem to indicate that the cooled gases were not receding from it indefinitely, but that a downrush of the outer layers had already occurred.

If the bright and dark lines of a *Nova* owe their origin to a series of eruptive prominences in the star, we should expect that the lines would be somewhat irregular in structure, and that these irregularities would vary from night to night. In the case of the dark lines this would be due largely to the existence of bright lines behind them, which they more or less completely conceal. This effect is readily noticeable in the photographic spectra, and is described also by Dr. Vogel (ASTRONOMY AND ASTRO-PHYSICS, 1893, p. 901).

If the light of the *Nova* was due chiefly to the presence of prominences, we should expect it to fluctuate appreciably from night to night. If the light was due chiefly to heat generated by a collision, it would be more uniform. The *Nova* first appeared, as

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shown by the Harvard photographs combined with one of Dr. Wolf's, about December 10, 1891. Ten days later it had doubled in brightness, and it continued to fluctuate, becoming alternately brighter and fainter for the next two months.

If we consider a bright line variable star to be one so far cooled, as to emit very large prominences only at stated periods, as does our Sun for instance, we may consider a *Nova* to be one still further cooled, emitting them perhaps for the last time, but with such intensity that the included gases recede in all directions, forming an atmosphere of extreme tenuity, but whose depth may possibly be measured by hundreds of millions of miles. Such a body, when it had reached a state of equilibrium would resemble planetary nebula in appearance, and probably in its spectrum also.

HARVARD COLLEGE OBSERVATORY,
January 25, 1894.

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THE AREQUIPA OBSERVATIONS OF *MARS* AND *JUPITER*.

BY

PROFESSOR W. H. PICKERING.

[Reprinted from *Publications of the Astronomical Society of the Pacific*, Volume VI, 1894.]

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THE AREQUIPA OBSERVATIONS OF *MARS* AND *JUPITER*.

By Professor W. H. Pickering.

In the *Publications* A. S. P. for June, under the title "The Lowell Observatory in Arizona," Professor Holden criticises the observations made by myself and my assistant in Arequipa in 1892. My reply is based upon an examination of a proof-sheet which he has very kindly forwarded to me. As far as the criticism relates to the planet *Mars*, it appears to be at least in part a personal one. Personal controversies seem to me to be ill-suited to the pages of an astronomical magazine, but under the circumstances, I may perhaps be allowed a few words in reply, before dealing with other matters.

It is true that two years have already elapsed, and a full report of our observations has not as yet appeared. This is, I presume, also the case with the work of the Lick Observatory, since I have thus far seen only fragmentary articles by the various members of its corps of astronomers. I am in hopes that a full report upon our work, with illustrations, will appear in less than twelve months.

Fragmentary articles have also appeared, by the Arequipa observers, and it seems to me a little strange that Professor Holden should not have referred to them, instead of criticising the necessarily imperfect accounts of our work which were transmitted by cable. As is perfectly well known, a cable despatch consists merely of a disconnected series of words, the grammatical construction and finish being supplied by the newspaper staff. Some mistakes were almost necessarily made in deciphering the despatches, such as the one pertaining to "trouble in the Arean clouds," cited by Professor Holden, but as a whole I think that the *Herald* staff did their work remarkably well. Nevertheless, I do not expect to hold myself responsible for all the details of the wording of the telegrams, when precisely the same facts are stated in my own words in so well-known a periodical as *Astronomy and Astro-Physics* (Vol. XI, 1892, pages 668 and 849). The cablegrams were sent to inform other astronomers and the general public of the character of the work that we were doing, and to call the attention of the former to certain facts that we had

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observed, in the hope that they might confirm them while the planet was still near to us. A more detailed report was given later, as above noted, and a full report of all our observations will appear before long in a volume of the Annals of Harvard College Observatory.

As an instance of the injustice of basing a criticism of the Harvard work upon a mere cable despatch, let us take Professor HOLDEN'S first statement. He says: "'The *Herald* correspondent at Valparaiso cables as follows: 'Professor PICKERING of the Harvard Branch Observatory at Arequipa says that he discovered forty small lakes in *Mars*.' How does he know the dark markings are lakes? Why does he not simply call them dark spots? And is he sure there are forty?'" Now, if Professor HOLDEN had examined my article upon the subject in *Astronomy and Astro-Physics* for 1892, page 850, he would have read: "Scattered over the surface of the planet, chiefly on the side opposite to the two seas, we have found a large number of minute black points. * * * * Over forty of them have been discovered, and for convenience we have termed them lakes." We should have liked to have put all this into our cablegram, but instead we simply said "forty lakes." It does not seem to me that the word lake is objectionable. It has already been applied by SCHIAPARELLI to several of the larger dark areas upon the planet, *Solis Lacus*, *Lacus Phœnicis*, etc. The forty smaller bodies discovered in Arequipa differed apparently from those mentioned by SCHIAPARELLI, chiefly in size.

The same remarks apply to Professor HOLDEN'S criticism of the mountain chains. In the above-mentioned article, upon page 851 he will find the statement: "At present the snow is divided into two sections, one long and narrow, the other of irregular shape, and somewhat mottled. The appearance is such as might be produced by a mountain range and an area of irregular elevation, with a valley lying between them."

Regarding Professor HOLDEN'S criticism of our cloud observations, I may state that upon August 5 and 6, and also upon September 10, 12 and 13, small portions of the *limb* were seen to project beyond the general contour of the planet. As I understand it, the only previous similar observation was made at the LICK Observatory, and was due to the discovery of a visitor, who noticed a white point projecting beyond the *terminator*. (*Publications* A. S. P., Vol. VI, page 104.) Upon September 13, I

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recorded: "7^h 05^m Arequipa Mean time. Two distinct elevations not less than 0".1, nor more than 0".2. * * * Tried 700 diameters. Think projections do not exceed 0".1, but cannot be much less." Later Mr. DOUGLASS observed them, and at 10^h 15^m I write: "The northern projection is very conspicuous, and before Mr. DOUGLASS had told me what its peculiarity was, I thought I could possibly distinguish a dark line separating it from the planet. * * *" This dark line is well shown in a sketch made by Mr. DOUGLASS at 9^h 33^m.

Neither do I consider Professor HOLDEN'S effort to disparage the Harvard drawings, as compared to those made at the LICK Observatory, justifiable. I did not send finished india ink sketches to *Astronomy and Astro-Physics*, but merely line drawings, knowing that they could be published more cheaply, and yet would serve to illustrate my remarks. The Harvard drawings were not selected with a view of showing what fine detail we could see, but merely to show the changes exhibited by a certain region upon closely successive nights. The *Solis Lacus* region of *Mars*, sketches of which are exhibited by Professor HOLDEN, is the region showing perhaps the greatest amount of fine detail to be found anywhere upon the planet, and I think that our drawings of it indicate quite as many lakes and canals as do the drawings published by the LICK Observatory. In any case comparisons are odious, and I prefer to let our drawings, when published, speak for themselves, rather than to discuss the matter further at present.

Regarding the Arequipa observations of *Jupiter's* first satellite, the facts of especial note that we derived were two-fold:

(*a*) We stated that the satellite had the form of a prolate ellipsoid, or, popularly speaking, was egg-shaped.

(*b*) We stated that, unlike our Moon, it rotated upon its axis in a period different from that of its revolution around its primary.

Turning now to the *Publications* A. S. P., Vol. III, pages 355 and 359, we find that Professors SCHAEBERLE and CAMPBELL announce that Satellite I "is ellipsoidal, that its largest axis is directed toward the center of *Jupiter*." That is, they appear to agree with statement (*a*), but deny statement (*b*). These results are quoted from Professor HOLDEN'S paper in *Astronomy and Astro-Physics*, 1894, page 357.

On the other hand, in *Monthly Notices*, Vol. LIV, page 135,

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and again in *Astronomy and Astro-Physics*, 1894, page 274, Professor BARNARD, also observing with the 36-inch telescope, denies statement (*a*), but apparently confirms statement (*b*), for he says: "From peculiarities in the appearance of the belt, it is probable that the period of rotation on this axis is not coincident with the satellite's period of revolution about *Jupiter*."

Now, with such discordant statements emanating from three such eminent observers, all using the same telescope. I think many persons would be interested if Professor HOLDEN would state definitely what he considers to be the verdict of the great LICK telescope upon these two disputed points. As far as Mr. DOUGLASS and myself were concerned, using our Arequipa instrument, our results were always concordant upon these points, and appeared to each of us at the time unmistakable. Of course, we neither claim superior eyesight, nor an equal instrument. Can the difference be due to the atmosphere, which at Arequipa was almost always very steady? I can offer no other explanation of the circumstance, and merely state what appeared to us to be the facts.

But one point remains to which I wish to draw attention. Regarding the shadows of *Jupiter's* satellites, Professor HOLDEN says: "They are seen at certain times to be twice as long as they are broad, and this phenomenon is regularly observed here. I believe it was not noticed in Peru, which is strange, considering how much more difficult observations are reported." Why Professor HOLDEN should say that this phenomonon was not noticed in Peru, or where he got his information, I cannot conceive. I certainly do not remember ever writing anything which could convey such an impression. In point of fact, the appearance was so easy to perceive, and its explanation was so obvious, that we rarely even mentioned it in our records. In looking over my observations, however, I find a few notes upon the subject, among others, under date of November 18, 1892, the entry, "8^h 06^m.—A very elongated shadow has just appeared upon *Jupiter*." This proved to be the shadow of the second and smallest of the four original satellites. A later entry, under the same date, reads "8^h 30^m.—Shadow of the second is equatorially elongated, but not so much so as it appeared when first seen on the limb of the disc." This phenomenon was apparently first observed and explained by an amateur, Mr. BARNEBY, of England, who, on April 5, 1861, recorded the change of shape

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of the shadow of the third satellite, from an elongated streak to a circular spot. (*Chambers' Astronomy*, 4th ed., Vol. I, page 190.)

In making this reply to Professor HOLDEN'S criticism of my work, I have taken up in sequence all the points raised that seemed most important to me, and treated them as briefly as possible. I hope that no further discussion of the matter will be necessary. Professor HOLDEN, as he truly remarked, spoke courteously, but very plainly. I am glad that he did so, as it has given me an opportunity to endeavor to do the same. As I am sure he meant no personal offense in making his somewhat severe criticisms of the Harvard observations, so I in turn trust he will take none at my rejoinder.

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COMPLIMENTS OF THE AUTHOR.

STARS HAVING PECULIAR SPECTRA.

M. FLEMING.

Reprint from ASTRONOMY AND ASTRO-PHYSICS, No. 119.

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STARS HAVING PECULIAR SPECTRA.*

M. FLEMING.

An examination of photographs of stellar spectra recently received from Arepuipa, Peru, taken under the direction of Professor S. I. Bailey, and forming part of the Henry Draper Memorial, has added the objects of interest given in the following table to the list of those already known. The designation of the star is given in the first column, and is followed by its approximate position in right ascension and declination for 1900. The catalogue magnitude is given in the fourth column and a brief description of the spectrum in the last column.

Design.	R. A. 1900 h m	Dec. 1900 ° ′	Mag.	Descr.
A.G C. 6519	5 31.7	−25 48	8	Type IV.
D.M. −29°2538	5 47.2	−29 19	9.3	Type III, hydrogen lines bright.
A.G.C. 8679	6 51.3	−42 14	6.7	Type IV.
B.D. −10°1786	6 53.2	−10 38	7 3	F line bright.
A.G.C.13554	9 51.6	−57 15	8½	Type V.
A.G.C.13665	9 56.7	−59 44	7¾	Type IV.
—— ——	10 6.1	−62 5	—	Type V.
—— ——	10 14.4	−62 9	—	Type V.
—— ——	10 22.9	−58 8	—	Type V.
A.G.C.19745	14 29.5	−42 56	8½	Type IV.

D.M. − 29° 2538 has a photographic spectrum of the third type having also the hydrogen lines bright. Measures of the brightness of this star on photographs taken October 15, October 21, November 3, 1889; December 8, 1892; and March 18, 1893, give the magnitudes 9.4, 9.6, 10.0, < 11.4, and 7.9 respectively, thus proving its variability.

A.G.C. 13554, and the stars whose approximate positions for 1900 are in R. A. 10^h $6^m.1$, Dec. − 62° 5′, R. A. 10^h $14^m.4$, Dec. − 62° 9′, and R. A. 10^h $22^m.9$, Dec. − 58° 8′, have spectra of the fifth type, consisting mainly of bright lines, and these added to those already announced increase the known number of these objects to fifty-five. The galactic longitudes of these stars are 248° 43′, 253° 0′, 253° 51′, and 252° 42′, and their galactic latitudes − 2° 19′, − 5° 14′, − 4° 46′ and − 0° 46′ respectively.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., September 12, 1893.

* Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

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Stars Having Peculiar Spectra.

M. FLEMING.

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STARS HAVING PECULIAR SPECTRA.

M. FLEMING.

An examination of photographs of stellar spectra, taken at the Peruvian station of Harvard College Observatory under the direction of Professor S. I. Bailey, and forming part of the work of the Henry Draper Memorial, has added several faint objects to the list of stars having peculiar spectra. The designation of the star is followed by its approximate right ascension and declination for 1900, its catalogue magnitude and a brief description of its photographic spectrum.

Designation.	R. A. 1900 h m	Decl. 1900 ° ′	Magn.	Description.
BD. + 30° 591	3 49.1	+ 30 46	6.5	Hβ bright
A.G.C. 13539	9 51.3	− 41 7	7½	Type IV
A.G.C. 19254	14 7.4	− 53 28	7½	Type IV
.....	16 24.7	− 40 2	...	Gaseous Nebula.
S.D. − 21° [illegible]	16 55.6	− 21 40	9 5	Gaseous Nebula.
Z.C. 17h 2657	17 40.8	− 35 40	8	Type IV
A.G.C. 24406	17 52.7	− 36 0	7.2	Hβ bright.
S.D. − 15° 4923	18 13.6	− 15 39	9.0	Type IV
S.D. − 13° 5083	18 38.7	− 13 20	9.1	Type V
BD. +11° 4673	21 46.2	+ 12 9	7.7	Hβ bright.

BD. +30° 591. The spectrum of this star also shows a bright line superposed on the edge of shorter wave-length of the line Hγ which is dark.

S.D. −21° 4483. An observation of this object on May 10, 1894, with the 15-inch equatorial, by Mr. O. C. Wendell, confirms the photographic results. Its visual spectrum is the same as that of other gaseous nebulæ and it presents a hazy disk when seen with a high power.

A.G.C. 24406. The spectrum of this star shows a bright line superposed on the edge of greater wave-length of each of the lines Hγ and Hδ, which are dark.

S.D. − 13° 5083. This star like all others of the same class lies near the central line of the Milky Way, its Galactic longitude being 348° 1′ and its Galactic latitude − 5° 55′.

BD. + 11° 4673. The spectrum of this star shows the lines Hγ and Hδ also bright.

New Variable Stars. Three new variable stars have also been discovered in this examination by means of the presence of bright hydrogen lines in their photographic spectra. In the table the constellation is followed by the approximate right ascension and

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declination for 1900, the magnitude when brightest and when faintest, as derived from the photographs at present at the Observatory, and the number of plates examined.

Constell.	R. A. 1900	Decl. 1900	Photog. Br.	Magn. Ft.	No. Plates
	h m	° ′			
Carina	9 54.8	− 58 23	8.2	9.6	24
Carina	10 10.4	− 58 21	9.4	12.1	18
Centaurus	12 28.0	− 54 6	9.2	11.3	16

The first of these stars is A. G. C. 13624, Magn. 8.

It must be here understood that the stars in the above table are not here announced as "suspected" variables since each of them appears bright on several plates and faint on several other plates. The variation has also been confirmed in each case by Professor E. C. Pickering. This is also the case with all the variable stars discovered here from the presence of bright hydrogen lines in their photographic spectra, with the exception of the star whose position for 1900 is in R. A. 15^h 27.0^m, Decl. -71^c 32′. (ASTRONOMY AND ASTRO-PHYSICS Vol. XII, p. 546).

Photographs of the spectra of the variable stars S Orionis, U Puppis, V Leonis, S Boötis, and R Phoenicis have been examined and show bright hydrogen lines. S Orionis and S Boötis were obtained from an examination of photographs taken with the 24-inch Bruce photographic telescope.

HARVARD COLLEGE OBSERVATORY,
Cambridge Mass., May 11, 1894.

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A New Star in Norma.

EDWARD C. PICKERING.

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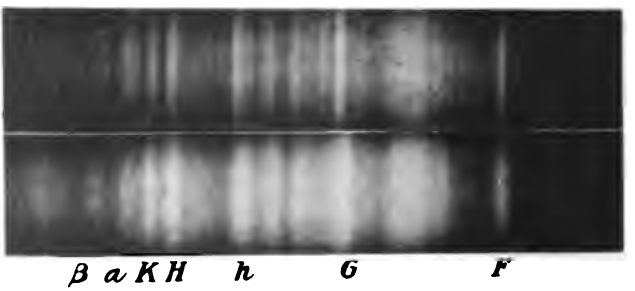
PLATE IV.

Nova Aurigæ, February 6, 1892.



Nova Normæ, July 10, 1893.

ASTRONOMY AND ASTRO-PHYSICS, January, 1894.

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A NEW STAR IN NORMA.*

EDWARD C. PICKERING.

A new star appeared in the constellation Norma during last summer. It was discovered by Mrs. M. Fleming on October 26, when examining a photograph of the spectra of the stars in its vicinity. The photograph was taken on July 10, 1893, at the Arequipa station of this Observatory by Professor Solon I. Bailey. The spectrum appears to be identical with that of the new star which appeared in Auriga in December, 1891. Comparing the spectra of the two stars taken with nearly the same dispersion, about a dozen lines are visible in each and are identical in wave-length. The hydrogen line F, which is bright in both stars, is more intense in the star in Norma than in that in Auriga. It is, in fact, more intense in the former star than any other line in the spectrum, while the G line is generally the strongest in Nova Aurigæ. A photograph taken June 21. 1893, showed the spectra of stars of the 10th magnitude, but no trace of the new star was visible upon this plate, although it covered the same region and was in other respects like that taken on July 10. Photographic charts of the same region taken on June 6, June 10, July 21, 1889; May 16, May 16, June 10, June 23, June 23, 1891; May 7, and May 27, 1893, show no image of this object although stars of the fourteenth magnitude are visible upon some of them. We may therefore conclude that the star appeared within ten days of the first of July and that previously it was either invisible, or extremely faint. The position was found by comparing the ends of the hydrogen lines, G and *h*, which are bright in this star, with the corresponding dark lines in the adjacent stars A.G.C. 20940 and 21006. They give the approximate mean position for 1900 in R. A. $15^h\ 22^m\ 12^s$; Dec. $-\ 50°\ 13'.8$. A more accurate position can be found if photographic charts can be taken showing this star. Professor Bailey has been notified of this discovery and if the star is still bright enough he will doubtless obtain photographs showing its position and spectrum.

The similarity of the spectra of these two new stars is interest-

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ing, first, since it has proved a means of discovering one of these objects, and secondly, because if confirmed by other new stars it will indicate that they belong to a distinct class resembling each other in composition or physical condition. The star was approximately of the seventh magnitude photographically on July 10 since it was about equal to A.G.C. 20910 magnitude 6.9 whose spectrum is of the second type. The nearest catalogue stars are A.G.C. 20940, magn. 8, which has a spectrum of the first type, and A.G.C. 20926, magn. 8¾, which has a spectrum of the second type. The new star lies nearly midway between these two.

CAMBRIDGE, Mass., U. S. A.
November 9, 1893.

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Photographic Determination of Stellar Motions.

E. C. PICKERING.

Reprint from ASTRONOMY AND ASTRO-PHYSICS.

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PHOTOGRAPHIC DETERMINATION OF STELLAR MOTIONS.*

EDWARD C. PICKERING.

A great advantage of photography as a means of studying astronomical phenomena is the ease with which a vast number of facts may be collected. These facts are recorded in permanent form and later may be deduced or verified. An attempt has accordingly been made at the Harvard College Observatory to detect by photography stars undergoing considerable change in position either owing to parallax or proper motion. Two methods have been employed for many years in comparing photographs of the same parts of the sky. First, by superposing two negatives of the same region, in which case the images of the stars will form curious sets of concentric circles, if the plates are not exactly oriented. Since the two films are separated by the the thickness of one plate of glass, small differences in position cannot readily be detected in this way. Secondly, if a contact print is made from one negative and the other negative is superposed on the positive thus formed, the dark images of one plate should fill the light spaces in the other, and give a nearly uniform surface. In actual practice this method was found here less satisfactory than might be anticipated, although highly recommended by Professor Barnard (*Astron. Nach.* CXXX, 77). A cluster appears to be the best object for this method. If the plates are not exactly superposed each star appears to project slightly from the background and to cast a shadow on one side.

A third method has accordingly been tried. A photographic plate is placed in the plate-holder with the film side away from the objective, the photograph being taken through the glass. The character of the images thus obtained does not seem to be affected. Theoretically, the plate-holder should be moved towards the objective by two-thirds the thickness of the plate, but this correction is scarcely perceptible, with a large telescope. When such a photograph is superposed upon a photograph taken in the us-

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ual way, the two films being placed together, all the images of one should appear to coincide with those of the other the difference in the planes of the two images not being noticeable even when viewed under a considerable magnifying power.

This last method has been in use for the past three years at the Harvard College Observatory with the 11-inch Draper telescope at Cambridge and with the 13-inch Boyden telescope at Arequipa. A number of objects, about a hundred and fifty in all, have been selected, including variable stars of long period, of short period, Algol stars, stars whose spectrum is of the third, fourth or fifth type, binary stars, stars having large proper motion, etc. The two dates are computed on which the longitude of the Sun should differ 90° from the longitude of each of these objects. Within a few days of each of these dates, two photographs are taken one with the plate in the usual position, the other with its film reversed. Generally, an exposure of about ten minutes was given to each. The first of these plates was taken in August, 1891.

The examination is made by superposing one plate upon another taken six months later and in the opposite position. Thus a plate taken in January with the film turned toward the objective is placed upon the plate taken in July with the film turned from the objective. The other two plates are also superposed. Instead of making the images exactly coincide, one plate is moved so that all of its images shall be exactly north of those on the other plate by a very small amount, for example, 10″. The plates then appear to be covered with double stars having the same position angles and distances with components nearly equal in brightness. If now the two images of any star differ in brightness it may be variable, and if the position angle is different from that of the adjacent stars it may be suspected of proper motion, or of sensible parallax. In any case, confirmation may be obtained at once from the other pair of plates. A third pair of plates should always be taken one or more years after one of the first dates and thus serve to distinguish between parallax and proper motion. In the actual examination a microscope is used having a field rather more than a centimetre in diameter and traversed by a vertical cross-wire. Sweeps are made moving the plate in right ascension, and after each sweep changing the declination by moving the plate one centimetre at a time, until the whole plate has been examined. As each star in turn is brought past the cross-wire the direction of the line connecting its components is determined with much accuracy. The diameter of the images should not exceed two to four seconds of arc and they

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may be placed about ten seconds apart. A parallax of half a second will then change the position angle by about five degrees, a very noticeable quantity. The conditions under which the plates are taken give nearly the maximum value of the displacement in right ascension due to parallax. This corresponds to a change in position angle to which the eye is much more sensitive than to changes in distance. Any suspected objects are marked upon the photographs and confirmed or not on the other plates. If the change in position is real, the same method may be used with great advantage for determining its amount. In the usual method, it is necessary to measure the position of each star from several adjacent companions which involves measurements of several hundred seconds and the application of various corrections for difference of scale, orientation, differential refraction, etc. The results are then brought together and the outstanding differences are discussed. In the present case the work is purely differential. We have only to measure the position angles and distances of what appear to be double stars whose components are nearly equal and to which any convenient position angle and distance may be given. Personal equation dependent on position angle is evidently eliminated. Such effects as differences in scale of the two plates, error in orientation and differential refraction then appear only as linear terms whose values are readily determined. Incidentally an inspection of these plates shows that no slipping of the film is sensible, but such a source of error, if it occurred, would affect all determinations of position from photographs. Although considerable progress has been made in taking the photographs much time has not yet been spent in studying them. An examination has been made by Miss L. D. Wells of 1436 stars on eight pairs of plates, and shows that probably none of these stars have a parallax of as much as half a second. Ordinarily, a pair of plates can be examined in about half an hour.

A preliminary measure of the positions of the images of eight stars in the vicinity of the variable star T Cassiopeiæ, gave the average deviation of the uncorrected differences 0″.23 which would correspond to a probable error in the parallax of but little over a tenth of a second as derived from measures of a single pair of plates.

Evidently in a few years the value of these plates will be greatly increased as a means of measuring proper motions. In ten years the work should be repeated and a proper motion of one-tenth of a second would then give a displacement of a second, which, as shown above, would be readily detected by inspection and could be measured with accuracy.

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The question has presented itself how far it may be best to photograph the entire sky with the Bruce telescope with plates in both positions, for determining the proper motion of large numbers of stars. The advantages of this method increase in many respects with the focal length of the telescope. The ease with which photographs suitable for this work may be taken with any photographic telescope is the reason for the present publication of a description of this method.

HARVARD COLLEGE OBSERVATORY, Cambridge, U. S.
JULY 8, 1894.

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FORTY-NINTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR ELEVEN MONTHS ENDING SEPTEMBER 30, 1894.

BY

EDWARD C. PICKERING.

CAMBRIDGE, MASS.
PUBLISHED BY THE UNIVERSITY.
1894.

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REPORT.

To the President of the University:

Sir, — The present report relates to the period of eleven months beginning November 1, 1893, and ending September 30, 1894. Hitherto the reports of the Observatory have taken date on the first of November of each year, but to bring them more nearly into conformity with the practice of other departments of the University a change has been made this year to the first of October. The most important events of the year have been the practical trial of the Bruce telescope and the successful operation for several months of the Boyden meteorological station on the summit of the Misti, at a height of 19,200 feet. The Observatory is indebted to Mr. Z. A. Willard for a valuable gift, an astronomical clock, constructed by Simon Willard, Jr., of Boston. The subterranean vault intended as a clock room by Professor Bond has been reopened, and if it can be rendered sufficiently dry the clock will be placed there. It is expected that the accuracy of our time signals will thus be materially increased.

An incident to be regretted has been a series of criticisms of the photometric work of the Observatory, which has been published during the year in local newspapers and other periodicals. So far as these criticisms have a scientific character they are answered below. A larger amount of space than usual has therefore been assigned to the description of the work of the meridian photometer, although it constitutes only about one-tenth of the entire work of the institution.

Observatory Instruments.

East Equatorial. — The systematic observation of variable stars upon the system described in previous reports continues to be the principal work of this instrument; but the photometric observation of the eclipses of Jupiter's satellites and several other classes of observation are also carried on as before. The observations were made by Mr. O. C. Wendell, except those of 3 of the 21 eclipses observed photometrically during the year, which were made by the Director. The total number of eclipses already observed is 546. The wedge photometer was used in 36 series of observations, comprising 1680 measurements, for determining the brightness of 560 stars occurring in the Durchmusterung. About seven thousand

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measurements were made with a polarizing photometer, including determinations of the relative light of the components of 53 of the brighter double stars; determinations of the brightness of variable stars; and measurements to extend the photometric scale to faint stellar magnitudes, relative estimates being also made for the same purpose. In addition to this, a series of measurements has been begun on some southern double stars whose combined light was determined with the meridian photometer at the Arequipa Station. Over four hundred relative estimates of variable stars have been made, and between one and two hundred absolute estimates, principally when the stars were faint. The regular observation of seventeen circumpolar variables has been continued as in past years, and the scheme is gradually being extended to all the known variables of long period.

Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision, and that portion of the work relating to the zone between the declinations + 49° 50′ and + 55° 10′ has been completed. Volume XXXV. of the Annals of the Observatory, containing the first half of the journal of the zones, has been printed, and a second volume, to contain the remainder of this journal, will be printed during the coming year. The observations of fundamental stars, made in the years 1880 to 1883 inclusive, are largely reduced, and will probably be published within two years more. This will complete the publication of the work done by Professor Rogers with the meridian circle.

The reduction of the observations of the southern zone between the declinations — 9° 50′ and — 14° 10′ has been continued through the year. Investigations have been made with regard to systematic errors in the observations of the fundamental stars, dependent upon declination and upon magnitude, but for the present these investigations cannot be completed, since their results will be somewhat affected by the future publication of the definitive places of the fundamental stars, from observations made at other observatories. Provisional constants, therefore, determined without regard to the investigations just mentioned, are employed in the preliminary reduction of the zone stars, which will be sufficiently precise to indicate the stars requiring additional observations. The portions of this reduction which are now complete for the entire series of observations are as follows: — The observed times of transit, reduced to the central line of the middle tally; the means of the microscope readings, corrected for error of runs; the reduction to the centre of the

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field required by the transits over the inclined lines used in the observations for declination; and the correction for the curvature of the paths of the stars through the field, known as the reduction to the meridian. The meteorological terms of the correction for refraction have also been computed throughout. The work recently in progress has been the completion of the reductions for January, February, and March of each year, in the hope that this may be finished in season to allow observations for revision to be undertaken early in 1895.

Observation of β Persei and a series of other stars near it in right ascension were made on seventeen nights during the winter, and the reduction of these observations is approaching completion.

Meridian Photometer. — The reduction of the photometric measures of the southern stars observed by Professor S. I. Bailey in Peru, is now completed, and the catalogue containing the resulting magnitudes is in print. Observations have been made by the Director with the meridian photometer during about four hours on nearly every clear evening. The total number of series is 110, and of separate photometric settings 54,360. The observations of the first investigation undertaken with this instrument since its return from Peru are nearly completed. About six thousand stars have each been observed on at least three evenings. This catalogue includes all the stars of the Harvard Photometry, eighty lists of comparison stars for variables of long period, and various stars whose magnitude is desired by other astronomers. A study has been made of the atmospheric absorption, especially for very low stars, and its coefficient has been derived on each evening both for the southern and the northern stars. These values are now applied as corrections to the individual observations instead of adopting a mean value of the absorption. A new working list has been prepared of the stars north of $-40°$ whose magnitude according to the best authorities is 7.5 or brighter, and which have not already been observed with the meridian photometer. This list contains about fourteen thousand stars, of which about two thousand have been observed during the last year.

An attempt has recently been made by Mr. S. C. Chandler to prove that the photometric observations made with the meridian photometer have little value. (Astron. Nach. Vol. 134, p. 355, and Vol. 136, p. 85.) It appeared that certain variable stars were incorrectly identified and observations of faint adjacent stars were obtained when the variables were too faint to be seen with this instrument. He claimed that erroneous observations were made in the case of fifteen out of eighty-six variable stars, and from this drew the extraordinary

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inference that similar errors affected the entire catalogue of twenty thousand stars contained in the same volume, although nearly all of the latter stars were bright enough to be readily measured, and identified with certainty. The most complete answer to this criticism is the extensive comparison recently made at the Potsdam Observatory of the photometric magnitudes obtained at that institution with those obtained here. Since this comparison is based on a large number of ultimate determinations obtained at both observatories it seems to dispose of inferences drawn from a few cases of exceptional difficulty. The Potsdam astronomers state that only four catalogues of the brightness of the stars are complete and correct enough for comparison with their own results. These are the Durchmusterung, the Uranometria Oxoniensis, and the Harvard results given in Volumes XIV. and XXIV. As was to be expected, the Durchmusterung magnitudes proved to be much less accurate than those in either of the other catalogues. The numbers of stars contained in each of the three photometric catalogues which were also observed at Potsdam are Oxford, 691, Harvard XIV., 791, and Harvard XXIV., 801. After applying a correction for color, the numbers of stars in these three catalogues whose brightness differs by half a magnitude or more from the Potsdam values, are 21, 6, and 13 respectively. For this and other reasons it was concluded at Potsdam that the order of accuracy of the results of the three catalogues is first Harvard XIV., second Harvard XXIV., and third Oxford. (Potsdam Publications, Vol. IX., p. 501.) The minimum number of nights' observation on which the results of Harvard XIV. depend is three, of Harvard XXIV. two. A comparison has been made at this observatory of the various magnitudes of the 40 discordant stars named above, as given in the five catalogues, Oxford, Potsdam, Harvard XIV., Harvard XXIV., and the revision mentioned above of the Harvard Photometry. Taking means and residuals of the magnitudes of the stars contained in three or more of these catalogues, the average deviations become, when arranged in the order of their magnitudes, for Revised Harvard Photometry, 0.11, Harvard XIV., 0.15, Harvard XXIV., 0.18, Potsdam, 0.21, Oxford, 0.29. The number of cases in which each catalogue gives the greatest or least value is similarly for Revised Harvard Photometry, 5, Harvard XIV., 6, Harvard XXIV., 10, Potsdam, 19, Oxford, 20. The order in both cases is the same, and serves to indicate the relative accuracy of the results of these five catalogues, which is also shown graphically in Table I. In two cases only do the Harvard XIV. and Oxford measures differ more than half a magnitude. Numerous other tests give a similar result. (See Astron. Nach., Vol. 135, p. 217.)

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TABLE I. — NUMBER AND MAGNITUDE OF DEVIATIONS.

Order of Excellence.	Catalogue.	Number.	Average Deviations.	Number of Extremes.
I.	Revised Harv. Phot.	..	0.11	5
II..	Harvard XIV.	6	0.15	6
III.	Harvard XXIV.	13	0.18	10
IV.	Potsdam.	..	0.21	19
V.	Oxford.	21	0.29	20

TABLE II. — NUMBER OF STARS IN VARIOUS PHOTOMETRIC CATALOGUES.

Catalogue.	Years.	Number of Stars.
Herschel.	1835–38	149
Seidel.	1844–60	208
Wolff I.	1869–75	475
" II.	1876–83	970
Peirce.	1872–75	494
Pritchard.	1881–85	2784
Potsdam.	1886–93	3522
MERIDIAN PHOTOMETER CATALOGUES.		
Vol. XIV.	1879–82	4260
Vol. XXIII.–IV.	1882–88	20982
Vol. XXXIV.	1889–91	7922
Vol. XLIV. (?)	1892–94	6000±
Vol. LIV. (?)	1893–97(?)	14000±

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It is maintained that the meridian photometer possesses the same advantages in measuring the light of a star that the meridian circle does in measuring its position. In both instruments absolute values are determined directly, and they are obtained very rapidly. Stars are identified in the same way in both, rapidly and accurately, and in both the systematic errors are small even if the accidental errors are in some cases larger than those resulting from other methods. Stars can be observed with the meridian photometer under favorable circumstances nearly at the rate of one a minute, and the average deviation of the results thus obtained does not generally exceed one-tenth of a magnitude. The amount of material accumulated by the meridian photometer is shown graphically in Table II., which gives for the principal photometric catalogues hitherto published, and for those in preparation here, the designation, the years of observation, and the number of stars contained in each.

West Equatorial. — Observations of variable stars were continued by Mr. W. M. Reed with this instrument until February 11, 1894, since which time he has carried on the same work with the five-inch telescope belonging to Abbot Academy at Andover, Mass., the use of which was kindly granted for the continuation of the observations. The plan of the work comprises the observation of as many of the variable stars of long period as possible through all stages of their brightness. When any of them become too faint to be seen with the instrument employed by Mr. Reed, he reports the fact to this Observatory, where the stars are observed, so far as practicable, by Mr. Wendell with the large equatorial until they recover sufficient brightness to be again observed by Mr. Reed. The number of nights on which Mr. Reed has made observations is 123; the number of observations of variable stars is 1641; of comparison stars, 339; of stars at the limit of visibility, 70.

In addition to this work on variable stars, Mr. Reed observed 6 reappearances of satellites of Jupiter, all at Cambridge, and 22 telescopic meteors. He looked for aurora on every clear night when observations with the telescope were in progress, and recorded its presence on 12 occasions. On 10 dates he observed the phenomenon of Gegenschein and studied the faint bands of light in the zodiac. The satisfactory condition of the air at Andover, and the skill of the observer, are shown by the fact that he obtained observations of Gegenschein as late as May 11, and again, after it had passed the Milky Way, as early as August 5. No previous observations, so far as is known, have been made so near the same part of the Milky Way, except at Arequipa.

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Henry Draper Memorial.

The number of photographs taken with the 8-inch Draper telescope is 1657. The number taken in Peru with the 8-inch Bache telescope is 1708. All of the spectra photographed with these instruments have been examined by Mrs. Fleming. As a result seven variable stars, U Puppis, V Cancri, V Leonis, T Sagittarii, R Delphini, R Vulpeculae and R Phoenicis, have been shown to have the hydrogen lines bright in their photographic spectra. Unsuccessful attempts have been made to photograph the spectra of many other variables of long period when at maximum, and no image has been obtained. This has been found to be due in many cases to large errors in the ephemerides, and has been remedied by depending upon the observations of Mr. Reed and making the time of photographing each star depend upon its observed, instead of its predicted brightness. Eleven new variables have been discovered this year from the presence of bright hydrogen lines in their spectra, besides three whose variability was discovered from changes in their photographic images. The number of stars of the fifth type has been increased by seven, making the total number of these objects 62. Five gaseous nebulae have been discovered from their spectra. The hydrogen line H β has been discovered to be bright in the spectra of five stars, and twelve stars have been shown to belong to the fourth type. The spectra of A. G. C. 18049 and 22640 are peculiar. Several photographs have been obtained of the new star in the constellation Norma, whose discovery was mentioned in the last report. At the Lick Observatory it was shown from visual observations that its spectrum, as in the case of the new star in Auriga, had become that of a gaseous nebula. This has been confirmed from photographs taken at Arequipa, which also show that this object is now gradually becoming fainter. The spectra of 4557 stars on 30 plates have been classified for the new Draper Catalogue. On one of these plates covering the region of the variable star η Carinae, 1161 spectra have been measured.

The number of photographs taken with the 11-inch Draper telescope is 912. The lines in the spectrum of ζ Ursae Majoris are found to be double in 59 out of 340 images, and of β Aurigae in 47 out of 65.

An investigation has been in progress for some time for the detection of stars having large parallaxes or proper motions. Photographs are taken in the usual position with the film towards the object-glass, and also with the plate reversed, the photograph being taken through the glass. These are repeated at intervals of six months at the times when the effect of parallax on their right ascension would have its greatest value. Plates thus obtained may then be superposed so that

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the films shall be in contact and the two images of each star made to appear like a close double with components north and south. Small changes in position may be detected by changes in the position angle, and the amount of the parallax or proper motion may be measured with great accuracy. Several hundred stars have thus been shown to have no parallax exceeding half a second.

Boyden Department.

The meteorological station on the Misti was successfully conducted for several months, one of the assistants, generally Mr. Waterbury, visiting it every ten days and readjusting the self-recording instruments. Unfortunately, early in September, the shelter containing the instruments was found to have been broken into and a number of the instruments carried off. Apparently the robbery was committed by two Indians whose tracks were followed to a considerable distance. The property stolen would of course be of no use to the thieves and its intrinsic value would be a small part of the actual loss. The work at this station was conducted with great labor, a mule path had been built to the summit and the entire expenditure had been large. It will be a serious loss to science if it proves impossible to maintain the station.

The number of photographs obtained by Professor Bailey with the 13-inch Boyden telescope is 561, including some remarkable charts. Among them may be mentioned photographs of the Nebula of Orion with an exposure of eight hours, of the cluster ω Centauri with an exposure of six hours, and of η Carinae with exposures of six and fourteen hours respectively. In some of these, notwithstanding the long exposure, the image shows no deviation from the circular form. This is mainly due to substituting for a finder two eyepieces attached to the main telescope. One of them serves to follow a guiding star in the usual way, the other directed to another star shows if the plate needs to be rotated in its own plane. This appears to be an important improvement in making the best photographic charts of long exposure, especially of the polar regions. By the ordinary methods it is impossible to entirely correct such errors as those due to flexure and refraction, which do not depend upon the direction of the axis of the earth.

Attention should again be drawn to the importance of availing ourselves of the admirable atmospheric conditions at Arequipa. A telescope of the largest size would not only have most favorable opportunities for work, but a field unexplored with such an instrument in the southern sky. Much could be done with a smaller instrument, as is shown by the work already accomplished with the

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13-inch Boyden telescope. Out of a list of thirty telescopes whose aperture exceeds 14 inches or more, but one is mounted south of latitude + 35° and this one is not in use. A moderate expense only would be required to carry out this plan.

The Bruce Photographic Telescope.

A careful trial has been made of this instrument and 936 photographs have been obtained with it. The spectra of the faint stars prove very satisfactory and stars too faint to be photographed with the other instruments can thus be studied. Bright hydrogen lines have been found in the spectra of S Orionis, S Bootis, W Virginis and S Librae, and the spectrum of V Ophiuchi has been shown to be of the fourth type. The length of these spectra is about a quarter of an inch, which is sufficient to show much detail in the spectra of fairly bright stars. To study still fainter spectra a prism of crown glass and of smaller angle has been ordered. The absorption of the photographic rays is less for this material and it is expected that much fainter spectra can be photographed, since the dispersion will also be less. The contract has not yet been filled for the Bruce telescope, since difficulty is still experienced in making charts in which the images shall be circular. Experiments are in progress in this direction and it is hoped that the method described above as applied to the 13-inch Boyden telescope will prove equally successful with this instrument.

A variety of experiments has been made to determine the photographic magnitudes of the brighter stars on a uniform scale. It is now expected that this can be done with the transit photometer for stars brighter than the third magnitude, and that the scale can be extended to stars from the third to the sixth magnitude by a series of photographs which are being taken with a portrait lens having an aperture of 2.5 inches. The images are thrown out of focus and the intensity of the circular disks thus obtained can be accurately measured.

Miscellaneous.

Library. — The library of the Observatory has been increased since the time of the last report by the addition of 218 volumes and 529 pamphlets. The total numbers of volumes and pamphlets on October 1, 1894, were 7710 and 9989 respectively.

As the station at Arequipa, Peru, will be maintained permanently, it is desirable, owing to its remoteness, that it should have a library of its own. Copies of astronomical and meteorological works sent there direct, or through this Observatory, will be gratefully received and will prove of much value.

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Telegraphic Announcements. — The distribution of telegraphic announcements of discovery has been continued as in past years, although Mr. Ritchie has resigned his position as Assistant in the Observatory. Astronomers are requested to continue to send to this Observatory announcements of their discoveries for transmission to the observatories of Europe and America.

Temporary absence of Observers. — Leave of absence, without salary, was granted on April 1st, 1894, to Professor W. H. Pickering and Mr. A. E. Douglass, in order that they might join the Lowell Observatory in Arizona. The 12-inch telescope and its stand were leased to Mr. Lowell from May 1st. No connection, however, exists between the two observatories.

Buildings and Grounds. — Since the time of the last report, a line of horse cars has been established on Concord Avenue, which forms the southern boundary of the grounds of the Observatory. The passage of these cars has no material effect upon the observations made here, but it is feared that the introduction of electric cars, which has been proposed, would be more detrimental. The widening of Concord Avenue, proposed last year, has not thus far been effected, and it is hoped that in any future change of that kind some means may be found of preserving the row of trees mentioned in the last report.

The electric lights, which seriously interfere with the observation of faint objects such as comets, nebulae, and zodiacal phenomena, prove an advantage in one way. They render visible faint clouds, which are carefully looked for every few minutes when the meridian photometer is in use. The effect is like that of the Moon, but as the lights are below the clouds instead of above them the latter become conspicuous even when too faint to be seen in moonlight.

Exhibition of Photographs. — The photographs sent to the Chicago Exhibition were safely returned, and by request were sent to California for exhibition at the Midwinter Fair. By the courtesy and aid of the Harvard Club of San Francisco and of Professor Holden, Director of the Lick Observatory, the photographs were successfully arranged for exhibition and safely returned.

Publications. — The printing of the following volumes of Annals of the Observatory has been finished: XXXV., containing the first half of the zone observations made by Professor Rogers between the declinations $+ 49° 50'$ and $+ 55° 10'$; XL., Part III., containing the

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Blue Hill Meteorological Observations for 1893; and XLI., Part I., containing a summary of observations made by the New England Weather Service in 1892. Volume XXXII., Part I., containing a discussion of photographic and visual observations by Professor W. H. Pickering is nearly completed. 201 pages of Volume XXXIV., which contains the observations by Professor Bailey of the brightness of 7922 southern stars, are in type. Volume XLI., Part II., containing a summary of observations made by the New England Weather Service in 1893, is in progress. A description of the meteorological station on El Misti appeared in two articles by Mr. A. Lawrence Rotch (American Meteorological Journal, X., 282, and XI., 187, 201); and a description by Mr. S. P. Fergusson of the pole star recorder in use here, appears in the same Journal, XI., 62.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-eighth Annual Report of the Director of the Astronomical Observatory of Harvard College. Cambridge, 1893.

The Ultra-Violet Hydrogen Spectrum. By W. H. Pickering. Astronomy and Astro-Physics, xii. 171.

The Total Eclipse of April 16th. By W. H. Pickering. Ibid. xii. 461.

Telescope Mountings and Domes. By W. H. Pickering. Ibid. xiii. 1. Reprinted in Observatory, xvii. 73.

A Study of Nova Aurigae and Nova Normae. By W. H. Pickering. Ibid. xiii. 201.

Melting of the Polar Caps of Mars. By W. H. Pickering. Ibid. xiii. 308. Reprinted in Observatory, xvii. 173.

The Forms of the Discs of Jupiter's Satellites. By W. H. Pickering. Ibid. xiii. 423.

The Seas of Mars. By W. H. Pickering. Ibid. xiii. 553.

Jupiter's First Satellite. By W. H. Pickering. Astronomische Nachrichten, cxxxv. 227.

South American Meteorology. By W. H. Pickering. American Meteorological Journal, X. 343.

The Arequipa Observations of Mars and Jupiter. By W. H. Pickering. Publications of the Astronomical Society of the Pacific, vi. 221.

Les Satellites de Jupiter. By W. H. Pickering. L'Astronomie, xii. 468.

The Harvard Observatory in Peru. By W. H. Pickering. Harvard Graduates Magazine, ii. 350.

A Climb in the Cordillera of the Andes. By W. H. Pickering. Appalachia, vii. 205.

Observations of Comets 1892 I, II, III, V, VI, also 1893 I, II. By O. C. Wendell. Astronomische Nachrichten, cxxxiv. 175.

Ephemeris of Comet 1893 IV for January, 1894. By O. C. Wendell. Astronomy and Astro-Physics, xiii. 80.

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Ephemeris of Comet 1893 IV for March, 1894. By O. C. Wendell. Ibid. xiii. 255.

Ephemeris of Comet 1894 I for June, 1894. By O. C. Wendell. Ibid. xiii. 514.

A Convenient Naked-Eye Star Atlas. By O. C. Wendell. Popular Astronomy, ii. 47.

Stars having Peculiar Spectra. By M. Fleming. Astronomy and Astro-Physics, xii. 810.

Two New Variable Stars. By M. Fleming. Ibid. xiii. 195. Popular Astronomy, i. 324.

Stars having Peculiar Spectra. By M. Fleming. Ibid. xiii. 501.

Stars having Peculiar Spectra. By M. Fleming. Astronomische Nachrichten, cxxxv. 195.

A New Star in Norma. By E. C. Pickering. Ibid. cxxxiv. 101. Astronomy and Astro-Physics, xiii. 40. Reprinted in Publications of the Society of the Pacific, vi. 53.

The New Star in Norma. By E. C. Pickering. Astronomische Nachrichten, cxxxiv. 181.

Anderson's Variable in Andromeda. By E. C. Pickering. Ibid. cxxxiv. 347.

Maximum of χ Cygni. By E. C. Pickering. Ibid. cxxxv. 127.

Variable Stars near 47 Tucanae. By E. C. Pickering. Ibid. cxxxv. 129.

New Variable Stars in Sculptor, Scorpius, Ophiuchus and Aquila. By E. C. Pickering. Ibid. cxxxv. 161.

The Photometric Catalogues of the Harvard College Observatory. By E. C. Pickering. Ibid. cxxxv. 217.

New Variable Star in Carina. By E. C. Pickering. Astronomical Journal, xiii. 79.

New Variable Star in Carina. By E. C. Pickering. Ibid. xiii. 147.

The New Star in Norma. By E. C. Pickering. Ibid. xiii. 398.

Photographic Determination of Stellar Motions. By E. C. Pickering. Ibid. xiii. 521.

The Astronomical Observatory. By E. C. Pickering. Harvard Graduates Magazine, ii. 241.

The Astronomical Observatory. By E. C. Pickering. Ibid. ii. 394.

The Astronomical Observatory. By E. C. Pickering. Ibid. iii. 87.

EDWARD C. PICKERING, *Director*.

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On the Forms of the Disks of Jupiter's Satellites

S. I. BAILEY

CHICAGO
The University of Chicago Press
1895

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ON THE FORMS OF THE DISKS OF JUPITER'S SATELLITES.[1]

By S. I. BAILEY.

EARLY in 1894 I attempted to make some observations on the forms of the disks of Jupiter's satellites, using the thirteen-inch refractor of the Arequipa Observatory.

Owing to the exceptional persistency of the cloudy season at that time I was able to observe them on a few nights only, and when Jupiter was low in the western sky.

In Arequipa the seeing after midnight is usually bad, which prevented exact observations toward the close of that year before the beginning of the cloudy season.

During the early months of 1895, however, these satellites were observed under reasonably good conditions. Below are given the dates and times of observation, and a summary of notes. The time given is Arequipa mean time:

January 17, 10:00–12:00 P.M. All four satellites round, except that I, before occultation, appeared elongated in same direction as Jupiter. No change in appearance of II, III and IV. Seeing, 4; scale, 1–5.

January 25, 8:00–10:00 P.M. All four round, except that I, before transit, seemed slightly elongated in same direction as Jupiter, but an hour later in transit looked perfectly round. Seeing, 4.

February 20, 10:00–11:15 P.M. All four apparently elongated slightly in same direction and amount. Seeing, 3–4. Adjustment of lens not perfected since reversal.

March 11, 7:30–10:00 P.M. All four round. No change. Seeing, 4.

March 13, 8:30– 9:10 P.M. II, III and IV in moments of best seeing; round.

March 19, 8:00–10:10 P.M. All four round; no changes.

March 22, 8:00– 9:00 P.M. Through clouds. In best seeing all four round.

March 24, 7:30– 8:40 P.M. Tendency to elongation of all, but round in moments of best seeing. Seeing, 2–3.

[1] Communicated by Edward C. Pickering, Director of Harvard College Observatory.

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March 27, 9:00–9:45 P.M. Seeing poor; 2–3. In best seeing, round. II and III close together. Occasional apparent distortion of form shared perfectly by both.

April 13, 7:00–9:45 P.M. All round. Seeing, 2–3.

April 14, 7:00–8:30 P.M. I, II, III and IV round in best seeing.

Consecutive observations for a larger number of hours during any one night were prevented by the clouds which are prevalent during these months.

In nearly all cases my own observations were confirmed by either Mr. H. C. Bailey or Mr. W. B. Clymer, assistants in this Observatory, and sometimes by both.

The results of our observations may be summed up as follows:

Under the best conditions, *i. e.*, with the instrument in perfect adjustment and good seeing, 3–5 on a scale of 1–5, II, III and IV were always seen round. I was twice seen having an apparent elongation in the same direction as Jupiter. In both cases the satellite was near the planet. On the second occasion, January 25, I, when off the disk but near Jupiter, appeared elongated, but an hour later, plainly seen on disk of Jupiter appeared perfectly round. On the other hand the shadows of I and III, on other nights were seen elongated.

Several occultations and transits were observed, but the limb of Jupiter was not seen, when, to me, it gave any indication of transparency.

The power usually employed was 800, but frequently higher and lower powers were also used. The conditions were not considered suitable for work of value, unless the image of a star in focus presented a central circular disk and sharply defined concentric diffraction rings. Under such conditions the components of close doubles, such as Bu 220, could be easily and distinctly separated.

During the hours given above we failed to detect any systematic change of form in any of the satellites. These observations, scattered through the cloudy season, may not be the best possible, for the same observers and instrument, in Arequipa;

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nevertheless, it does not seem to me probable that any frequent periodic recurrence of an ellipticity, approximating in amount that of Jupiter itself, would have escaped detection.

Although the above observations were the only ones regarded of special value, it may not be out of place to refer to certain difficulties incidentally met. The thirteen-inch refractor is used for both visual and photographic work. To change from one class to the other it is necessary to remove the lenses and reverse the crown glass. After the use of the lenses for photographic work it is impossible to immediately replace them in perfect position for visual work. The final adjustments require a certain time. When the adjustment is very close, but not perfect, the image of a bright star in focus presents no sensible wings, but the image, when just out of focus, is slightly irregular in form. Under such circumstances I have noticed that if the seeing is good and the images exactly in focus, the disks of the satellites appear round, *i. e.*, are unaffected in form by the slight lack of adjustment,—but, that, with poor seeing or with the images a little out of focus, there is a slight elongation in the same direction as that of the out-of-focus stellar image. The tiring of the eye would, perhaps, have the same effect as a slight change of focus at the eyepiece. When the altitude of the object observed was very low, both in double star and satellite observations, an elongation has been sometimes noticed similar to that caused by lack of adjustment, and perhaps for the same cause. In all such cases, however, the elongation, when present, was shared by all the satellites in common.

AREQUIPA, May 1, 1895.

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Stars Having Peculiar Spectra. Eleven New Variable Stars

M. FLEMING

CHICAGO
The University of Chicago Press
1895

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STARS HAVING PECULIAR SPECTRA.[1]

ELEVEN NEW VARIABLE STARS.

By M. FLEMING.

AN examination of the photographs of stellar spectra taken at Arequipa, Peru, under the direction of Professor S. I. Bailey, and forming part of the work of the Henry Draper Memorial, has, during the last few months, shown marked peculiarities in the spectra of eleven objects enumerated in Table I, and has resulted in the discovery of eleven new variable stars enumerated in Table II. The first column of Table I gives the designation of the object and is followed by the approximate right ascension and declination for 1900, the catalogue magnitude, and a brief description of the photographic spectrum:

TABLE I.

Designation	R.A. 1900	Dec. 1900	Mag.	Description
Z.C. 3^h 1404	$3^h\ 46^m.7$	$-43°\ 50'$	8.5	Type IV
S.B.D.—22° 1070	5 14 .5	−22 19	8.7	Peculiar
N.G.C. 2070	5 40 .5	−69 43	..	Bright lines, Gas. Neb.
A.G.C. 8518	6 46 .1	−32 24	4.0	*Hβ* bright
A.G.C. 9181	7 10 .2	−26 10	5.4	*Hβ* bright
.....	7 19 .5	+ 9 7	..	Bright lines, Gas. Neb.
Cord. D.—31° 5004	7 41 .1	−31 41	9.2	Type V
Z.C. 7^h 2999	7 42 .0	−34 8	9.5	Bright lines, Gas. Neb.
.....	16 16 .8	−51 18	..	Type V
.....	16 39 .8	−67 36	..	Type IV
Z.C. 17^h 734	17 13 .2	−66 15	8.5	Peculiar

The gaseous nebula whose approximate position for 1900 is in R.A. $7^h\ 19^m.5$, Dec. $+9°\ 7'$ was found in the examination of the photographs taken with the 8-inch Draper telescope at Cambridge.

[1] Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

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The stars contained in Table II have a spectrum of the third type, having also the hydrogen lines bright, and their variability was at once suspected from this peculiarity. Conclusive evidence of their variation, as shown below, was in each case obtained on examination of chart plates of these regions. They are not here announced as suspected variables, but as variable stars, the variation, in each case, having been confirmed independently from an examination of the photographs by Professor Edward C. Pickering. The first column gives the constellation, and the second, the catalogue designation. This is followed by the approximate right ascension and declination for 1900, the number of photographs examined, and the maximum and minimum photographic magnitude as derived from the photographs:

TABLE II.

Constell.	Designation	R.A. 1900	Dec. 1900	No. Plates	Mag.	
					Max.	Min.
Tucana	.....	$0^h\ 18^m.4$	$-62°\ 14'$	15	8.7	<11.6
Pictor	*A.G.C.* 5428	4 43 .5	−49 25	16	8.1	9.5
Lepus	*S.B.D.*—22° 995	5 0 .6	−22 2	13	8.2	10.9
Pictor	*Z.C.* 5^h 283	5 8 .3	−48 38	16	8.6	<13.3
Scorpius	.....	17 35 .1	−43 42	37	9.3	12.7
Telescopium	.....	20 7 .6	−47 18	7	8.4	11.6
Indus	*Z.C.* 20^h 1539	20 49 .0	−54 42	26	8.4	<12.4
Octans	.....	20 57 .4	−82 30	28	9.0	<12.5
Grus	.....	21 42 .1	−47 22	25	8.4	<12.5
Aquarius	.....	22 13 .2	−21 26	18	8.4	11.6
Phœnix	*A.G.C.* 32334	23 53 .9	−57 8	22	7.2	8.7

—Tucanae, R.A. $0^h\ 18^m.4$, Dec. $-62°\ 14'$. The magnitudes of this star as derived from photographs taken on September 11, October 8, November 28, 1889; September 12, September 23, 1890; August 20, September 17, October 4, October 4, October 26, 1891; July 31, September 5, 1892; October 23, 1893; July 6, and July 23, 1894, are <10.9, 10.6, 9.4; 9.4, 9.7; <10.7, <11.3, <11.5, <11.6, 11.3; 8.7, 9.2; <10.3; 8.8 and 9.0 respectively.

—Pictoris, *A.G.C.* 5428. The magnitudes of this star as

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derived from photographs taken on September 26, September 26, October 4, October 8, 1889; September 23, 1890; October 26, 1891; September 28, September 29, December 8, 1892; November 18, 1893; August 21, August 25, September 14, September 19, September 19, and October 19, 1894, are 8.5, 8.3, 8.5, 8.6; 8.8; 8.6; 8.6, 8.6, 9.5; 9.0; 8.1, 8.2, 8.4, 8.5, 8.5, and 8.9 respectively.

— Leporis, *S.B.D.*— 22°995. The magnitudes of this star as derived from photographs taken on November 4, November 17, 1889; February 3, September 19, September 19, December 29, 1890; January 26, 1891; November 18, 1893; September 14, October 24, 1894; March 5, March 9, and March 16, 1895. are 9.2, 8.4; 9.4, 10.5, 10.3, 8.4; 9.4; 8.2; 10.4, 9.0; 10.9, 10.8, and 10.8 respectively.

— Pictoris, *Z.C.* 5^h 283. The magnitudes of this star as derived from photographs taken on September 26, September 26, October 8, November 6, 1889; September 23, 1890; October 24, November 23, 1891; September 28, October 6, December 8, 1892; September 27, September 27, November 18, 1893; September 14, September 19, and November 5, 1894, are <10.8, <11.1, <11.8, <12.7; <13.2; <13.3, <11.4; 11.5, 12.0, <13.3; 10.6, 10.6, 11.4; 11.3, 11.0, and 8.6 respectively.

— Scorpii. R.A. 17^h $35^m.1$, Dec. −43° 42′. The magnitudes of this star as derived from photographs taken on July 9, July 9, July 13, July 17, July 19, July 20, July 21, July 22, August 6, August 28, 1889; May 9, June 9, June 9, 1890; May 18, May 18, May 19, May 19, September 8, 1891; April 19, June 6, June 10, 1892; April 27, May 1, May 1, May 8, May 8, June 24, 1893; May 23, June 1, June 1, June 1, June 1, June 14, July 20, July 20, August 14 and September 21, 1894, are 9.9, 9.8, 9.8, 9.6, 9.8, 9.6, 9.5, 9.5, 9.3, 9.6; 11.4, 10.7, 10.8; <11.8, <10.7, 12.4, <12.2, 9.6; <11.1, 10.8, 10.8; <11.1, 12.6, <11.6, 12.7, <12.4, 11.5; <12.3, <12.1, <11.8, <11.6, <11.3, <12.3, 11.4, 11.2, 10.7 and 9.9 respectively.

— Telescopii. R.A. 20^h $7^m.6$, Dec. −47° 18′. The magnitudes of this star as derived from photographs taken on July 24, 1893;

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July 21, August 21, September 12, September 15, September 15 and September 27, 1894, are 8.7; 11.6, 11.6, 9.0, 9.1, 8.9 and 8.4 respectively.

—Indi. *Z.C.* 20^h 1539. The magnitudes of this star as derived from photographs taken on June 20, July 5, July 19, July 21, July 22, August 22, October 26, 1889; May 21, May 22, June 2, June 10, June 10, July 16, 1891; September 8, September 8, September 8, 1892; June 27, July 31, July 31, September 23, September 23, 1893; May 21, July 13, July 25, August 11 and August 11, 1894, are 10.3?, <11.3, <12.3, <11.9, <11.6, <12.4, <9.9; 11.3, 11.7, <12.1, <10.4, 12.0, <10.2; <11.1, <12.2, <12.2; 10.2, 11.3, 11.4, <12.2, <12.3; 8.4, 9.3, 9.7, 10.1 and 10.1 respectively.

—Octantis. R.A. 20^h $57^m.4$, Dec. $-82°$ 30′. The magnitudes of this star as derived from photographs taken on June 17, June 18, June 20, August 8, September 4, September 16, September 27, October 1, 1889; June 9, June 13, June 14, August 5, September 5, 1890; June 11, June 11, June 11, June 14, June 19, October 19, October 19, 1891; May 3, June 23, 1893; July 16, July 16, August 2, August 13, August 14 and September 10, 1894, are 12.4, 11.8, <11.7, <10.8, <10.4, <10.3, <12.3, <11.8; 9.8, 9.5, 9.5, 10.3, 12.0; <11.2, <10.4, <12.5, <10.9, <12.5, 10.6, 10.6; <12.5, 9.8; 11.3, 11.2, 9.0, 9.1, 9.0 and 9.1 respectively.

—Gruis. R.A. 21^h $42^m.1$, Dec. $-47°$ 22′. The magnitudes of this star as derived from photographs taken on June 20, June 20, July 13, July 13, July 13, July 18, July 18, July 22, September 11, September 28, October 8, 1889; June 12, 1890; May 20, June 8, June 8, June 8, June 13, July 16, 1891; October 6, October 6, 1892; July 24, July 24, August 21, August 21, 1893; May 21 and August 31, 1894, are <10.5, <10.5, <11.1, <11.5, <11.7, <12.4, <12.5, <12.3; <11.6, <10.5, <11.7; 11.9; <11.8, <10.5, <11.8, <10.1, <10.8, <12.2; 8.8, 8.8; 11.8, 11.7, 10.2, 10.6; <11.6 and 8.4 respectively. The magnitude 10.2 on August 21, 1893, may be somewhat in error since the image of the variable is near the edge of the plate, thus rendering the comparison difficult.

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$-$Aquarii. R.A. $22^h\ 13^m.2$, Dec. $-21°\ 26'$. The magnitudes of this star as derived from photographs taken on August 28, September 3, September 25, September 27, September 30, September 30, October 24, 1889; July 7, July 10, 1890; June 14, June 16, 1891; July 3, 1892; September 20, September 20, October 25, October 25, 1893; August 10 and August 11, 1894, are 10.0, 10.0, <10.6, 10.6, 10.8, 10.8, 11.6; 10.0, 9.9; 10.9, <10.6; <10.4; 9.4, 9.4, 9.3, 9.3; 8.5 and 8.4 respectively.

$-$Phoenicis. *A.G.C.* 32334. The magnitudes of this star as derived from photographs taken on July 17, August 20, September 11, October 8, October 8, 1889; June 30, August 20, August 20, August 21, September 17, 1891; May 16, May 16, August 16, September 5, 1892; July 24, July 27, August 21, September 20, September 27, October 23, November 17, 1893; and July 24, 1894, are 8.2, 8.4, 8.4, 7.2, 7.5; 8.7, 7.8, 7.7, 8.2, 8.3; 8.2, 8.2, 8.4, 8.4; 8.4, 8.2, 8.2, 8.1, 8.3, 8.2, 8.6; and 8.0 respectively.

The magnitudes given above for the new variable star in Aquarius were derived from the mean of two or more measures made independently on two different dates, and using a different set of comparison stars when the variable was faint. The average difference of these measures is $\pm$ .09.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., April 9, 1895.

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January, 1895

Photographic Observations of Eclipses of Jupiter's Satellites

By W. P. GERRISH

CHICAGO
The University of Chicago Press
1895

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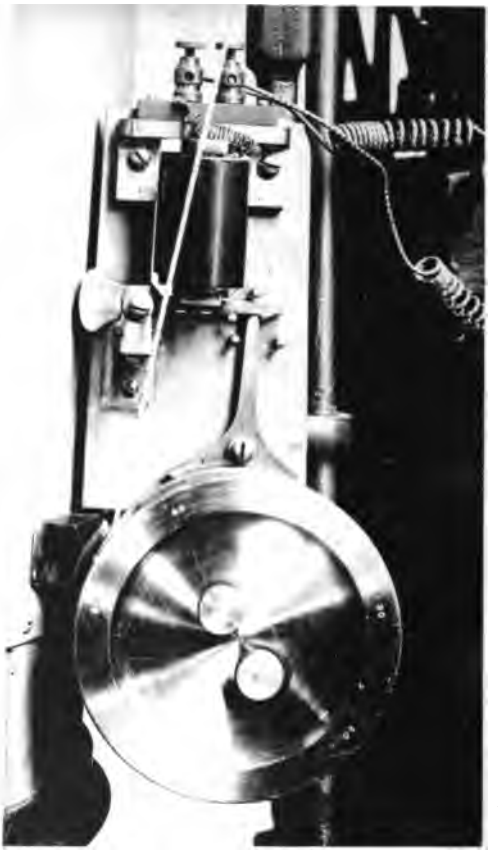

FIG. 1

FIG. 2

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PHOTOGRAPHIC OBSERVATIONS OF ECLIPSES OF JUPITER'S SATELLITES.[1]

By WILLARD P. GERRISH.

SINCE the year 1878 systematic observations have been made at the Harvard College Observatory of the eclipses of Jupiter's satellites. The variation of the apparent magnitude of the satellite, as it entered or emerged from the shadow, was determined by visual observations taken in rapid succession by means of a polarizing photometer attached to the 15-inch refractor.

Since the recent successful applications of photography to photometric research, it was decided to make photographic observations of all these eclipses visible at Cambridge, and the 11-inch Draper photographic telescope was chosen as being best adapted to the requirements of the work. The instrument is a visual refractor with a photographic correcting lens, the photographic focal length being about 144 inches. It is provided with an electrically controlled driving clock. It was found upon experiment that an exposure of ten seconds with this instrument was sufficient to give satisfactory images of the satellites, and a plan of observation was arranged upon that basis. The observation of a disappearance was conducted by exposing a plate upon Jupiter about eight minutes before the computed time of the eclipse, the telescope being kept directed by its driving clock. The slow motion in declination was then moved by hand at intervals of ten seconds, the time being taken from a chronometer. The motion was of sufficient rapidity to insure distinct, detached images of the satellites without the use of an exposing shutter, and was gauged to produce a displacement of the image on the plate of about 0.8 of a millimeter. This amount was doubled on the sixtieth second of each minute, thus dividing the chain of images into groups of six, each group representing one minute of time. The

[1] Communicated by Edward C. Pickering, Director of Harvard College Observatory.

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exposures were continued for ten minutes in the case of the first and second satellites, the time being somewhat extended in the case of the third and fourth. Reappearances were observed in the same manner. By this method a continuous series of images was obtained, having a uniformity of exposure which admitted of direct photometric comparison, besides giving a faithful record of the beginning or ending of the period during which the satellite was too faint to be photographed. After completing an observation, short independent series of exposures were made upon the same plate, with the aperture of the telescope reduced by known amounts. In this way a valuable check was obtained upon the scale of magnitudes used.

The success of the photographic method just described suggested the use of an attachment which should be entirely automatic in its action, and the apparatus shown in the accompanying photograph (Plate VIII) was designed by the writer. A drum, four inches in diameter, is attached to the tangent screw of the slow motion in declination. Upon the drum is wound a cord, leading along the side of the telescope tube, through a pulley at the junction of the polar and declination axes, and thence to a weight of sufficient size to readily turn the drum. As the pulley is at the center of oscillation of the telescope, the telescope tube can be moved without affecting or being affected by the tension upon the cord. As the drum revolves under the influence of the weight, steel pins inserted in its inner edge engage successively the three-armed locking lever shown in the photograph. The upper end of the lever is held in position by a hook on the armature of a small electromagnet. The lever is similar in its action to an ordinary anchor clock-escapement. The drum turns in a direction corresponding to that of the hands of a watch, until stopped by a pin coming in contact with the left-hand arm of the locking lever. The end of this arm is slightly inclined, so that the lever, if free to swing, would be thrown aside, allowing the pin to pass. When an electric current is sent through the coils of the magnet the hook is lifted by the armature, freeing the lever, which is promptly

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thrown to the right by the action of the pin, thus unlocking the drum. The pin thus released passes along under the right-hand arm of the locking lever, returning the lever to its original position, where it is caught by the hook and is in readiness to receive the next pin. This device makes it possible to control a considerable weight with a small magnet and light current, though the pressure ordinarily exerted by the cord upon the drum is about one pound. The pins on the drum are six in number, and the spaces between them are equal, with the exception of that between the sixth and first, which is double that of the others, allowing the telescope to move twice the usual amount at the end of each minute, as already described. The electric signals operating the magnet are given at intervals of ten seconds by a special clock connection. In the small photograph is shown a portion of the photographic record of an eclipse which occurred on December 10, 1892. The telescope in this case was operated by hand. The new apparatus is designed to give a similar record. The images in the photograph are enlarged to about three times the scale of the originals.

HARVARD COLLEGE OBSERVATORY,
December 14, 1894.

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Discovery of Variable Stars from their Photographic Spectra

By E. C. PICKERING

CHICAGO
University of Chicago Press
1895

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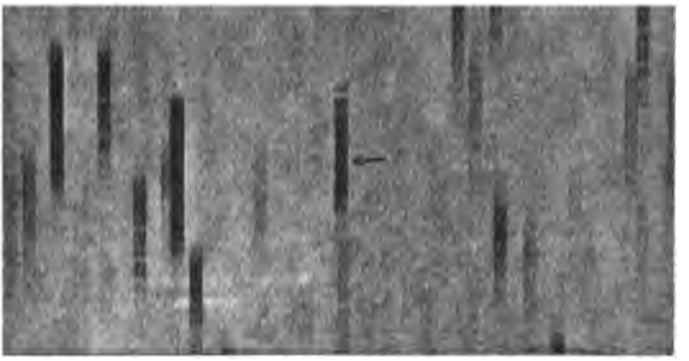

FIG. 1

FIG. 2

FIG. 3

PHOTOGRAPHS OF THE VARIABLE STAR *O. A.* 16,121 AND ITS SPECTRUM, TAKEN AT AREQUIPA, PERU

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DISCOVERY OF VARIABLE STARS FROM THEIR PHOTOGRAPHIC SPECTRA.

By EDWARD C. PICKERING.

An illustration of the method employed at the Harvard College Observatory, during the last five years, for discovering variable stars of long period from their photographic spectra is shown in Plate III. The spectra of a large part of this class of variables are of the third type, and when near maximum the hydrogen lines are bright. With perhaps a single exception, no star has yet been found having this class of spectrum which has not proved to be variable. The Henry Draper Memorial furnishes every year photographs of the spectra of many thousands of stars. From an examination of these spectra Mrs. Fleming has discovered thirty-four new variable stars, and has shown that sixty-five known variables have a similar spectrum. No star has been assumed to be variable from its spectrum, but in each case, on the examination of photographic charts of the region, taken on different days, marked changes in brightness have been found. The variation has also, in every case, been confirmed by the writer before announcement of variability has been made.

A photograph of the spectrum of *O. A.* 16,121, which is *Cord. DM.* -30° 13,626, in the constellation Scorpius, and whose approximate position for 1900 is R. A. $= 16^h\ 50^m.3$., Decl. $= -30^\circ\ 26'$, shows the hydrogen lines $H\gamma$ and $H\delta$ bright on plate B 10,104. This photograph was taken with the Bache Telescope at Arequipa, Peru, on August 6, 1893, exposure 60^m. It is represented in Plate III, Fig. 1, enlarged three times, so that the scale is $1' = 0^{cm}.1$ (nearly). The arrow indicates the spectrum of the variable, and also points to the hydrogen line $H\gamma$, which is bright, and therefore appears dark in the print, which is a negative. The line $H\delta$ is also seen to be bright and is about $0^{cm}.55$ below $H\gamma$. The bright star of the first type $2^{cm}.6$ to the left

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of the variable is *Cord. DM.*$-30°$ 13,564 mag. 6.8. The principal lines shown in the spectrum of this star are $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$, K, $H\zeta$, $H\eta$, etc.

Enlargements of charts of the same region, and on the same scale, are given in Figs. 2 and 3. They are made from plates B 6073 and B 3802, taken on May 28, 1891, and July 13, 1889, with exposures of 10^m each. In Fig. 2 the star is bright, while in Fig. 3 it is so faint as to be scarcely visible. Its maxima are represented by the formula J. D. 2,395,466 + 278 E. (See *A. N.* **135**, 161). Fifteen other photographs of the region show the variable in different degrees of brightness from the magnitude 7.3 to 11.6. The evidence regarding the other thirty-three variables mentioned above as discovered by this method is equally conclusive.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Dec. 14, 1894.

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Comparison of Photometric Magnitudes of the Stars

BY E. C. PICKERING

CHICAGO
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1895

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COMPARISON OF PHOTOMETRIC MAGNITUDES OF THE STARS.

By Edward C. Pickering.

In the ninth volume of the publications of the Observatory at Potsdam the photometric magnitudes obtained at that institution are compared with the results of three other photometric catalogues. These are the *Uranometria Oxoniensis*, the *Harvard Photometry* (*Harvard Annals*, Volume XIV) and the results contained in Volume XXIV of the *Harvard Annals*. From this it appears that the number of stars in each of these catalogues observed also at Potsdam is 691, 791, and 801 respectively. The number of cases in which the difference exceeds half a magnitude, after applying a correction for the systematic difference due to the color of the stars, is similarly 21, 6, and 13 in the three cases. As this correction is almost exactly the same for the *Oxford* and *Harvard* catalogues, it has been found convenient in the following table to apply the correction for color to the *Potsdam* magnitudes. As no comparisons are made in the *Potsdam* volume of the magnitudes of the stars observed both at Oxford and Harvard, it seems worth while to give them below, especially as later observations of many of these stars have also been obtained at Harvard in the re-observation, now nearly completed, of all the stars contained in the *Harvard Photometry*.

In the following table the forty stars mentioned above, and enumerated in the *Potsdam* volume (page 500), are given on successive lines. The number from the *Potsdam* catalogue in the first column is followed by the magnitudes in the five catalogues mentioned above. They are arranged in chronological order, as the mean year of observation of the *Harvard Annals*, Volume XIV, is 1881, of the *Uranometria Oxoniensis*, 1884, *Harvard Annals*, Volume XXIV, 1885, *Potsdam Observations*, 1890, and the revision of the *Harvard Photometry*, 1893. The means and residuals of these magnitudes are given in the subsequent columns when a

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OXFORD, POTSDAM.

	1881 Harv'd XIV	1884 Oxf'rd	1885 Harv'd XXIV	1890 P'tsd'm	1893 Rev. H. P.	Mean	Residuals				
10	3.04	2.47	2.77	3.02	2.85	2.83	+.21	−.36	−.06	+.19	+.02
318	5.78	5.72	..	6.22	6.14	5.96	−.18	−.24	..	+.26	+.18
332	2.68	2.44	2.93	2.93	2.80	2.76	−.08	−.32	+.17	+.17	+.04
638	..	6.06	..	7.22	..	..	..	..	..	..	..
849	5.66	5.61	..	6.12	5.89	5.82	−.16	−.21	..	+.30	+.07
899	4.40	4.89	4.38	4.36	4.13	4.43	−.03	+.46	−.05	−.07	−.30
984	4.62	5.19	4.71	4.63	4.50	4.73	−.11	+.46	−.02	−.10	−.23
990	5.62	5.45	6.02	5.98	5.91	5.80	−.18	−.35	+.22	+.18	+.11
1754	6.30	6.19	6.95	6.71	6.58	6.55	−.25	−.36	+.40	+.16	+.03
1813	5.59	5.65	6.04	6.18	6.27	5.95	−.36	−.30	+.09	+.23	+.32
1917	6.61	6.30	6.74	6.82	6.81	6.66	−.05	−.36	+.08	+.16	+.15
2171	..	7.13	..	6.56	6.64	6.78	..	+.35	..	−.22	−.14
2610	..	3.91	..	4.73	4.56	4.40	..	−.49	..	+.33	+.16
2611	..	4.23	..	5.16	..	..	..	..	..	..	..
2622	5.24	5.03	5.57	5.56	5.44	5.37	−.13	−.34	+.20	+.19	+.07
2756	6.64	6.31	6.81	6.88	6.64	6.66	−.02	−.35	+.15	+.22	−.02
2776	5.69	5.45	5.91	5.93	5.74	5.74	−.05	−.29	+.17	+.19	.00
3026	4.13	3.59	3.80	4.17	3.99	3.94	+.19	−.35	−.14	+.23	+.05
3327	5.18	4.99	5.50	5.50	5.25	5.28	−.10	−.29	+.22	+.22	−.03
3343	5.27	5.05	5.67	5.78	5.44	5.44	−.17	−.39	+.23	+.34	.00
3414	2.61	2.33	2.49	2.94	2.66	2.61	.00	−.28	−.12	+.33	+.05

HARVARD XIV, POTSDAM.

1737	6.75	6.47	6.30	6.25	6.41	6.44	+.31	+.03	−.14	−.19	−.03
1813	5.59	5.65	6.04	6.18	6.27	5.95	..	..	..	..	..
2044	5.71	5.79	..	6.25	5.90	5.91	−.20	−.12	.	+.34	−.01
2326	6.45	..	..	5.58	5.59	5.87	+.58	..	..	−.29	−.28
2918	6.01	6.00	..	5.50	5.91	5.86	+.15	+.14	..	−.36	+.05
3343	5.27	5.05	5.67	5.78	5.44	5.44	..	..	..	..	..

HARVARD XXIV, POTSDAM.

122	5.68	5.60	5.79	5.50	5.59	5.63	+.05	−.03	+.16	−.13	−.04
185	..	..	6.21	6.50	6.30	6.34	..	..	−.13	+.16	−.04
245	5.55	5.50	6.15	5.60	5.52	5.66	−.11	−.16	+.49	−.06	−.14
653	6.49	..	6.62	6.22	6.81	6.54	−.05	..	+.08	−.32	+.27
1218	..	..	7.71	9.05	..	..	..	..	..	..	..
1698	..	..	6.75	7.02	..	..	..	..	..	..	..
1699	..	..	7.70	7.56	..	..	..	..	..	..	..
1752	..	..	6.93	6.36	..	..	..	..	..	..	..
2395	..	..	6.48	5.98	5.83	6.10	..	..	+.38	−.12	−.27
2535	..	..	8.20	7.64	..	..	..	..	..	..	..
3094	..	..	6.91	7.73	..	..	..	..	..	..	..
3166	..	..	8.07	7.44	..	..	..	..	..	..	..
3361	3.59	3.29	3.78	3.48	3.42	3.51	+.08	−.22	+.27	−.03	−.09

Average deviations ..... ±.15 ±.29 ±.18 ±.21 ±.11

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star appears in more than two catalogues. Stars 1813 and 3343 appear twice in the table, and the residuals for the second entry are therefore omitted. Stars 122, 185, 653, 3327, and 3361 occur in both Tables I and IV of Volume XXIV, and the mean of the magnitudes is accordingly entered in the table.

From the average deviations given in the last line the order of excellence of the first three catalogues appears to be the same as that found at Potsdam, *Harvard* XIV first, *Harvard* XXIV second, and *Oxford* third. Moreover, the Potsdam observations are more accordant than the Oxford, and the recent Harvard work more accordant than any. The observations in Volume XIV were made with an instrument smaller and inferior to that used in the later Harvard work, but as the minimum number of nights' observations was three instead of two, the average deviations for Volumes XIV and XXIV do not differ greatly. It should be noticed that the above stars are in general the most discordant in the catalogues, as they include all the stars in which the results differ more than half a magnitude. The average deviations of the other stars would be much less. To treat the three catalogues, *Oxford*, *Potsdam*, and *Harvard* XIV symmetrically, stars differing in *Oxford* and *Harvard* XIV by half a magnitude should also be included. On examination it appeared that there were only two such stars, 984 and 3026, in the part of the sky here under discussion, and these are already included in the above list among the stars differing at Potsdam and Oxford. The Harvard results agree more closely with both the Potsdam and the Oxford measures than the latter do with one another, the number of differences in the three cases exceeding half a magnitude being 6, 2, and 21 respectively. In the average deviations given below it might be thought that the results were affected by errors persisting in all the measures made with the meridian photometer. This would not be likely to occur, as two different instruments were used, and an interval of several years occurred between the second and third series, during which the instrument was dismounted and sent to South America, and a long series of measures made with it there. There is no evidence of such a persistence

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in the corresponding residuals. A recomputation has, however, been made, taking the mean of all the meridian photometer observations of each star, and giving equal weights to this mean, to the Potsdam, and to the Oxford results. The average deviations then become, for *Potsdam*, .21, for *Oxford*, .27 and for *Harvard*, .11. The differences in the three Harvard catalogues separately become, for Volume XIV, .17, Volume XXIV, .21, and for the revision of the *Harvard Photometry*, .12. The differences in the different catalogues cannot be mainly due to progressive changes in light of the stars, or we should expect the first and last catalogues to give the largest average deviations, also that the extreme values would occur most frequently in these catalogues. A count of these extreme values shows that the number for each catalogue is, for *Harvard* XIV, 6, for *Oxford*, 20, for *Harvard* XXIV, 10, for *Potsdam*, 19, and for the revision of the *Harvard Photometry*, 5. The order is again the same as for the average deviations.

The positions of 1698 and 1699 were interchanged in printing Volume XXIV. Their magnitudes as given in Volume XXIV have therefore been transposed in the above table, since the stars were entered correctly in the observing list, and correctly observed. In fact, on three of the four nights on which they were measured, the observer noted the position of the adjacent star. A large part of the errors of Volume XXIV, such as those relating to *B. D.*+59° 76 (*A. N.* **136**, 85) are of this class, the stars being correctly observed but the places incorrectly printed. Slight errors in the *Durchmusterung*, especially in declination, were often noticed by the observer, but even an error of a minute of time, as in the case of *B. D.*+45° 921, probably seldom led to the observation of another star, especially when, like *B. D.*+69° 455, it was near the pole. In this latter instance the error in the *Durchmusterung* of a minute of time only displaced the star 5′, or about one-ninth of the diameter of the field. Moreover, on both nights of observation the observer recognized the error by noting that the star had the same right ascension as *B. D.*+70° 497. Apparently some other star was observed by mistake for *B. D.*+5° 1934.

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An attempt has been made throughout the Harvard work to eliminate systematic errors as much as possible, since if this is done the accidental errors can be reduced indefinitely by increasing the number of observations of each star. The accidental errors in either catalogue are of little importance, since they affect the final values by only a few hundredths of a magnitude, while the systematic differences amount in some cases to several tenths. At Harvard, when an observation was discordant, the star was re-observed on so many nights that the final value was generally only changed one or two tenths of a magnitude, whether the observation was retained or rejected.

The Potsdam astronomers are in error in one respect, in supposing that the Harvard observations were made with undue haste. In quoting from Volume XXIII, p. 7, the statement of the speed attained, they have failed to quote the sentence following it. "Care was always taken that the observer should not be hurried in his measures, and the work was accordingly so divided that he generally had to wait for the recorder." A star a minute is not an unusual speed for observations of stars in zones with meridian circles, where much more accurate measures are required, and is never regarded as an evidence of inaccuracy. Under favorable circumstances stars can be observed at this rate with the meridian photometer, and the results will have an average deviation of almost exactly a tenth of a magnitude. Of course, several minutes are often spent upon a single star when adjacent stars render its identification uncertain. The great number of measurements obtained may be assigned to two causes. First, as in the case of other meridian instruments, very little time is lost in setting upon the star and identifying it with certainty, so that almost the entire time of the observer is spent in the actual photometric comparisons. Secondly, by long practice observers and recorders are enabled to perform the mechanical operations with great rapidity. The average number of stars, not including standards, observed each evening at Potsdam was eighteen, while at this Observatory, when the work is not interrupted by clouds, it now exceeds one hundred. To fairly compare the two methods

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the error of the mean of five or six observations made here should therefore be compared with that of a single observation at Potsdam. At Oxford ten stars were generally observed each night, four sets of measures being made of each star. The above discussion with that given elsewhere shows that the work done with the meridian photometer compares favorably with that obtained by other methods, both as regards speed and accuracy.

HARVARD COLLEGE OBSERVATORY.

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Reprinted from THE ASTROPHYSICAL JOURNAL for April, 1895

T Andromedæ

Eclipse of Jupiter's Fourth Satellite, February 19 1895

BY EDWARD C. PICKERING

CHICAGO
The University of Chicago Press
1895

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PLATE XIV

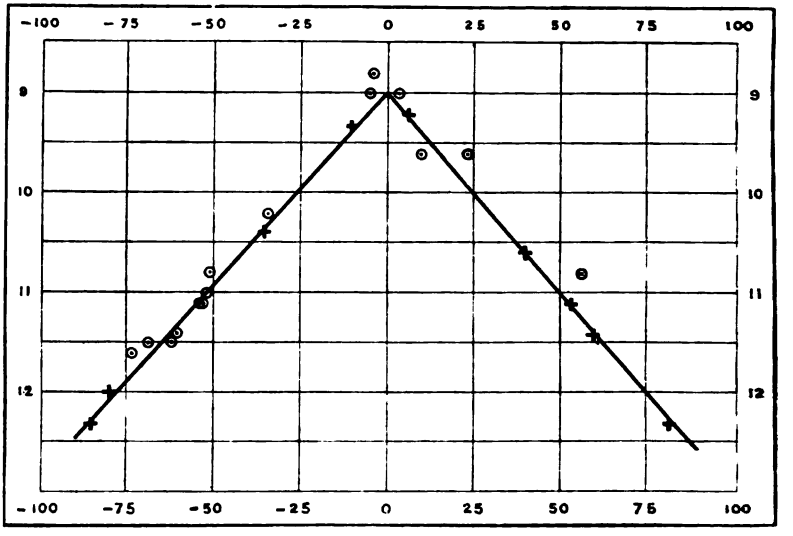

FIG. 1

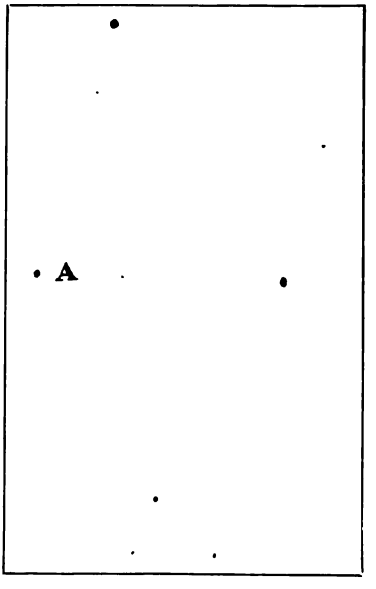

FIG. 2

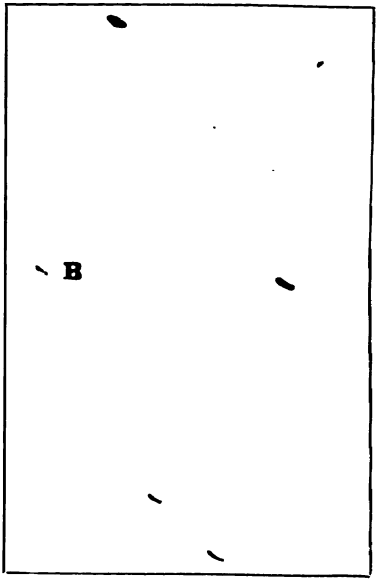

FIG. 3

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T ANDROMEDÆ.

By EDWARD C. PICKERING.

ON learning of the discovery by Mr. Anderson of the variable star T Andromedæ, an examination was made of the Henry Draper Memorial photographs of this object. The results were communicated to the *Astronomische Nachrichten* (**134**, 347), and, as there stated, indicate a photographic magnitude of 9.0 at maximum, and a very uniform increase and diminution in the light at the rate of one magnitude in twenty-six and twenty-five days respectively during the three months preceding and following the maxima. This form of light curve is confirmed by the photographs taken since then which are enumerated below. They also indicate a change in the period, the value 281 days, which satisfies the observations during 1891 to 1894, giving a maximum later than that which actually occurred in 1895. These results are represented in the following table, which gives in successive lines all the photographs so far obtained here of this star. Photographs of the region taken when the star was too faint to appear are not included. The dates and observed photographic magnitudes are followed by the maximum computed by the law given above. Thus the first plate was taken on the Julian Day 2,412,039. The magnitude 10.4 indicates that it was 1.4 magnitudes fainter than the maximum, and multiplying 1.4 by 26 gives 36, the time in which the maximum would be attained. Adding 36 to 2,412,039 gives 2,412,075, or 2,075 if we omit the constant 2,410,000. This quantity is entered in the third column. The mean of the individual values of each time of maximum is given in the next column, followed by the residuals found by subtracting it from the individual values. The residuals have the average value of $\pm$ 2.9 days, corresponding to a deviation of the observed magnitudes of $\pm$ 0.11. These values would be reduced one-quarter if we could reject the last three results. The latter are not due to errors of observation,

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since a second independent measurement gave the same result in each case within 0.05 of a magnitude, corresponding to a change of two days in the time of maximum. While these photographs fail to show whether the light curve is pointed or rounded at the exact time of maximum, they indicate that the curvature, if any, is inappreciable except within a few days of the maximum.

Date	Obs. Mag.	Max.	Mean	Resid.
1891 Nov. 2	10.4	2075	2074	+ 1
" " 27	9.3	2072		− 2
" Dec. 13	9.2	2075		+ 1
1892 Oct. 24	10.6	2356	2356	0
" Nov. 6	11.1	2357		+ 1
" " 13	11.4	2356		0
1893 Sept. 13	12.3	2638	2638	0
1894 Jan. 2	12.3	2917	2916	+ 1
" " 7	12.0	2914		− 2
" " 7	12.0	2914		− 2
" " 19	11.5	2913		− 3
" " 25	11.5	2919		+ 3
" Feb. 2	11.1	2917		+ 1
" Sept. 28	11.6	3168	3173	− 5
" Oct. 11	11.4	3175		+ 2
" " 18	11.1	3175		+ 2
" " 19	11.0	3173		0
" " 20	10.8	3169		− 4
" Nov. 6	10.2	3170		− 3
" Dec. 5	9.0	3168		− 5
" " 6	8.8	3169		− 4
" " 13	9.0	3176		+ 3
" " 20	9.6	3168		− 5
1895 Jan. 2	9.6	3181		+ 8
" Feb. 5	10.8	3185		+ 12

The form of light curve is shown in Plate XIV, Fig. 1, in which abscissas represent the times in days preceding or following the observed maxima, and ordinates the corresponding magnitudes. The assumed law is represented by the heavy line. The observations from which the form of light curve was inferred are represented by crosses, the later observations by circles.

If we take first differences of the times of maxima found above we find the intervals 282, 282, 278 and 257. The observations during 1891 to 1894 are therefore very well satisfied by the period 281 days. The observations of 1894 indicate a change

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in the period which cannot be accounted for by errors of observation. Rejecting the last two observations changes the mean time of maximum from 3173 to 3171.

The magnitudes given above are found by comparing the photographic images of the variable with adjacent comparison stars of nearly equal brightness and estimating the difference in magnitude. The comparison stars when the variable is bright are BD. + 26° 40, + 26° 47, + 25° 42 and + 25° 40. Their photographic magnitudes are 8.7, 9.2, 9.8 and 10.3. The positions and magnitudes of the fainter stars will be given elsewhere.

In a recent article in the *Astronomical Journal* (**14**, 183) Mr. P. S. Yendell describes his observations of this star and concludes that the period is 265.35 days. Since the photographic magnitudes do not accord with this theory, he derives the singular conclusion that they must be wrong, maintaining that some of them are in error by two or three magnitudes. He states that the light curve described above has a form which "is not only inherently improbable, but which actually proves to be incorrect.' Inherently improbable does not seem to be a strong argument in view of the variety in form of light curves of variable stars, especially as the linear form is strikingly confirmed by Nova Aurigæ and other variables (*A. N.* **134**, 138). It also represents one of the simplest theoretical laws, the variation in the energy being proportional to the energy itself. Furthermore it coincides with Newton's law of cooling. Whether the light curve is actually incorrect cannot be proved by observations made at a different time and on a different portion of the light of the star. As Mr. Yendell does not give the light curve he has himself deduced or even the names and magnitudes of his comparison stars, it is difficult to discuss it. It may be noted, however, that unless he measured the variable photometrically or used magnitudes photometrically determined for his comparison stars, it would be impossible for him to tell whether his light curve was linear or not, when represented on the scale of Pogson used here. The error in his assumed scale of magnitudes might easily introduce a marked deviation from a straight line in his

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curve. Mr. Yendell's table of observed maxima appears to me illusory. Two of these maxima are derived from the Harvard photographic magnitudes by a process which he does not describe, and give results which differ widely from those found here. It is surely impossible to infer from maxima thus obtained that the observations on which they depend are themselves sometimes in error by more than two magnitudes. If such errors exist, this determination of the maxima should have been rejected.

The photograph of this star taken on November 27, 1891, is represented in Fig. 2. The variable, A, is distinctly brighter than the two stars below and to the right, which are of about the tenth magnitude. The upper of these stars is BD. $+25^{\circ}$ 40. A defect in the original negative to the left of this star has been removed in the print without affecting the image of the star itself. The magnitude of the variable on this day according to the above table is 9.3. The photograph taken October 24, 1892, is represented in Fig. 3. The variable, B, is here fainter than the stars below. Its magnitude is given above as 10.6, or 1.3 magnitudes fainter than A. According to Mr. Yendell's theory on the first date the photographic magnitude 9.3 is too bright by 2.1 magnitudes, and its magnitude should have been 11.4. B similarly should have been 10.5, or 0.9 magnitudes brighter than A. An inspection of the plate will enable the reader to decide whether to believe that Mr. Yendell's theory or the photographic magnitudes are in error.

HARVARD COLLEGE OBSERVATORY,
CAMBRIDGE, MASS.,
March 5, 1895.

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ECLIPSE OF JUPITER'S FOURTH SATELLITE, FEBRUARY 19, 1895.

By EDWARD C. PICKERING.

PHOTOMETRIC observations of the satellites of Jupiter while undergoing eclipse have now been maintained at the Harvard College Observatory for many years. This method has special advantages in the case of the fourth satellite, owing to the slow variation in its light. The total number of eclipses of this satellite that can be observed from any one station is comparatively small. From April 16, 1892, to January 16, 1895, the satellite passed outside of the shadow of Jupiter and was not eclipsed. On January 16 Jupiter was below the horizon at Cambridge at the time of the eclipse. At the next eclipse on February 2 the night was cloudy.

On February 19, 1895, the fourth satellite was compared with the second satellite by means of a photometer consisting of a double image prism and Nicol (*Harvard Annals*, **11**, 4). Observations were made continuously from 28 minutes before to $26^m\ 42^s$ after the predicted time of disappearance, $13^h\ 23^m\ 18^s.4$ Greenwich Mean Time. Observations of the reappearance, which was predicted to occur at $14^h\ 58^m\ 52^s.0$ G. M. T., were prevented by clouds. The photometer was attached to the 15-inch telescope of the Observatory, and all of the observations were made by Mr. O. C. Wendell. In the annexed table the observations are arranged in groups in successive lines. Each group consists of twenty photometric settings, except the last, which consists of eight settings. The mean of the observed times minus the computed time of disappearance is given in the first column expressed in seconds, and the corresponding mean difference in magnitude of the fourth and second satellites in the second column. As the satellites are close together they would be equally affected by the clouds which interrupted the later observations. The deviations of the observed magnitudes

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A New Form of Stellar Photometer

EDWARD C. PICKERING

CHICAGO
The University of Chicago Press
1895

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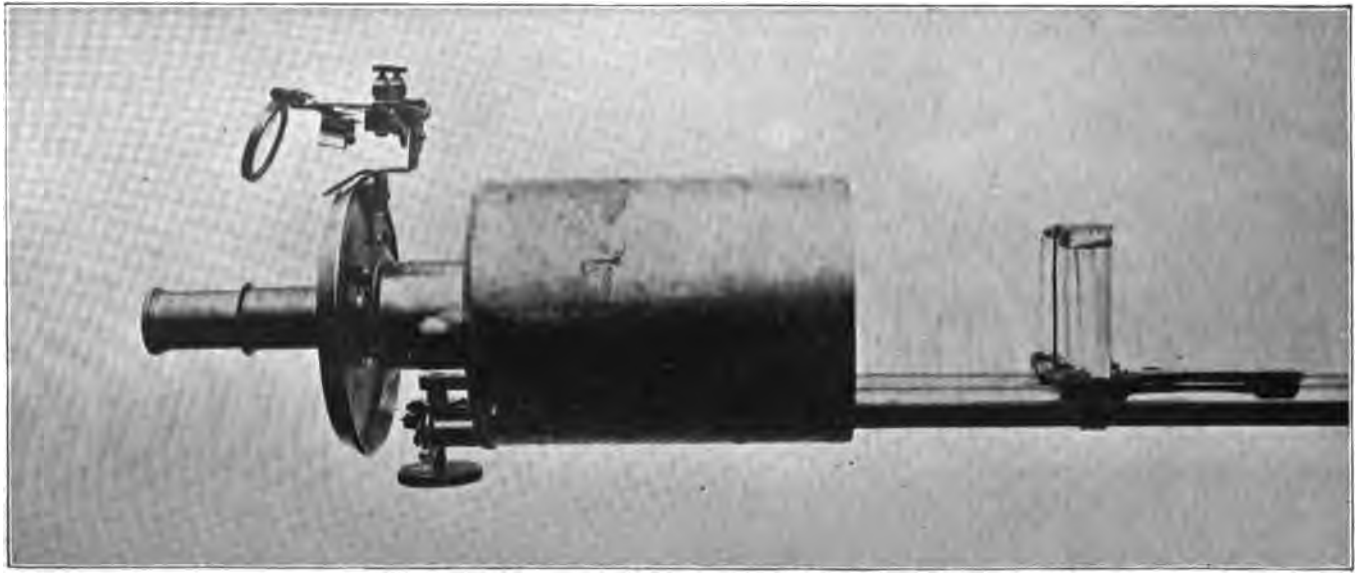
PLATE VI



A NEW FORM OF STELLAR PHOTOMETER

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THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME II AUGUST 1895 NUMBER 2

A NEW FORM OF STELLAR PHOTOMETER.

By EDWARD C. PICKERING.

In 1877 observations were undertaken at the Harvard College Observatory of the relative light of the components of double stars. The photometer chiefly employed is described in the *Annals* **11**, 1, Fig. 1, and is still in use. It consists of a double image prism which can be moved along the axis of the telescope to any desired distance from the focus and a Nicol prism in front of the eyepiece which can be turned by an amount which is measured with a graduated circle and index. This instrument leaves little to be desired in the measurement of close double stars. Nearly all sources of systematic error may be eliminated when it is properly used, and the relative brightness of two adjacent stars may be determined with great accuracy. Besides the measures given in Volume XI, this photometer has been used for many years in measuring the brightness of the satellites of Jupiter when undergoing eclipse and also for measuring variable stars and doubles. Examples of the accuracy attainable with it will be found in the *A. N.*, **134**, 348 and **135**, 127, from which it appears that the results on different nights will give average deviations considerably less than a tenth of a magnitude. This instrument gave rise also to the meridian

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photometer, which differs from it in principle only by bringing together the images of stars formed by two object-glasses instead of two images formed by the same object-glass, so that stars however distant can be compared. The same degree of accuracy is not, however, attainable with the meridian photometer, since owing to varying density of the air, haze, and other causes, the images of the stars compared will not resemble each other as closely when they are distant as when they are adjacent. A modification of the first of these photometers attached to the fifteen-inch equatorial enables two stars as much as 5′ apart to be compared. But this seems to be about the limit attainable with a telescope of this size. With a smaller telescope more distant stars may be compared, but of course only comparatively bright stars can then be measured. Three difficulties arise when the distance between the stars is large. First, the double-image prism must be large or a portion of the object-glass will be cut off and light thus lost when the prism is moved far from the focus. Secondly, the images will be colored and will in fact become short spectra, since the double-image prisms are not achromatic. The lengths of these spectra are nearly proportional to the apparent angular distance apart of the objects compared. When the stars differ in color, as frequently happens with double stars, the difference in the spectra introduces a new form of error. Thirdly, if double-image prisms having a large angle of separation are used to compare distant stars, the emergent pencils formed by the two images of the object-glass will only partly overlap and thus introduce a new source of error. A portion of one of the pencils may be cut off by the edge of the pupil of the eye, or the unequal transparency of different portions of the cornea may unduly diminish the light of one star.

All of these difficulties are avoided by the form of photometer represented in Plate VI. The double-image prism is placed at the focus, as in the meridian photometer, and the two images of the object-glass are formed by two achromatic prisms which can be slid by a chain and sprocket wheel to any desired distance from

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the focus. A screw is cut on the axis of the sprocket wheel, and turns a wheel which is divided so as to indicate the position of the prisms and accordingly the distance apart of the stars. A Nicol prism and eyepiece are placed behind the double-image prism, and the position of the Nicol prism is read by a graduated circle and index. A Foucault prism is in practice found preferable to a Nicol, since although the loss of light is slightly greater, the field is less restricted.

The angle of separation of the images formed by the double-image prism is nearly equal to the sum of the deviations of the achromatic prisms. The emergent pencil of the ordinary image of one, therefore, nearly coincides with the emergent pencil of the extraordinary image of the other, as in the case of the meridian photometer. As in that instrument the two remaining pencils are cut off by the eyestop. In fact the theory of this photometer is the same as that of the meridian photometer, the two images of the object-glass taking the place of the two object-glasses of the latter instrument. Both instruments have the same advantages as regards the possibility of eliminating nearly all forms of systematic error. The images of two stars may be brought together by moving the achromatic prisms towards or from the focal plane of the telescope and by rotating the whole photometer. Each set of measures consists of settings in the four positions of the Nicol prism in which the images of the two stars appear equal. The images are always brought near together and reversed between the second and third settings. After every eight settings the entire instrument is rotated 180°, since it is found that certain sources of systematic error are thus eliminated. Several sets of measures, generally four or six, are made of each object observed. This is found advantageous, since several minutes are always expended when setting a large telescope on a new object, in turning the dome, moving the chair, reading the circles, identifying the objects, and adjusting the photometer. When this is done it saves time to repeat the measures and thus reduce the accidental errors as much as possible. With the meridian photometer all these adjustments

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are made in a few seconds. It is therefore better with this instrument to take each evening only one, or at most two sets and repeat the measures on several evenings. But likewise, with the new photometer, each object is regularly observed on as many as three dates.

One-half of the light of each star is lost in the process of polarization. The losses by reflection and absorption of the various prisms used reduce the brightness of the stars by at least one magnitude. This is equivalent to a reduction of the aperture of the telescope by about one-third when the photometer is used. The faintest stars that can be measured with the fifteen-inch telescope are of about the 13.5 magnitude. When the greatest accuracy is desired the difference in brightness of the stars compared should not exceed five or six magnitudes, although it is possible to measure as large intervals as eight or nine magnitudes. In the photometer represented in Plate VI, the images are separated 4° by the double-image prism. The achromatic prisms are about six centimeters on a side and the deviation of the light which they occasion is about 2° 15′. They may be moved about 90 centimeters along the axis of the telescope. Their combined deviation is somewhat greater than that of the double-image prism when they are brought near it, but it is less when they are moved to the other end of the photometer. The two emergent pencils exactly coincide only for a certain position of the prisms, but they never separate by an amount likely to cause error. When the prisms are at their greatest distance from the focal plane the images of two stars 35′ apart may be brought together. This distance becomes 3′ when the prisms are moved near the double-image prism. In either extreme position the field is somewhat limited, since a portion of the emergent pencil may be cut off if the image is not in the center of the field. This is best tested by covering the center of the object-glass and throwing the stars out of focus. Their images will then appear as circular rings of light which will be broken, that is, will become incomplete circles, if any portions of the cones of light are cut off.

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Since stars as distant as 35′ may be compared, at least one star as bright as the eighth or ninth magnitude would probably always be available for comparison. The brightness of this star can afterwards be determined with the meridian photometer and the scale of that instrument thus extended to any star brighter than the fourteenth magnitude. In this photometer the two stars are compared directly; the accidental errors should therefore be less than in the Zöllner photometer and similar instruments, in which each star in turn is compared with another source of light.

This photometer is now attached to the fifteen-inch equatorial of this Observatory. It is regularly used on almost every clear night by Mr. O. C. Wendell, who made the observations described below in three tests which have been made of the instrument.

As the first of these tests, three stars were selected, *B.D.*+79° 169,+79° 171 and a star of the eleventh magnitude preceding *B.D.*+79° 169 by 29ˢ.9 and north 7′.8. The brightness of each of these stars was then compared with the other two. The difference in brightness of the first and third exceeds six magnitudes and is as great an interval as can be accurately measured. Four sets of four measures each were made on May 3, 6, 29 and June 10, 1895, with the results 6.24, 6.40, 6.38 and 6.48. The mean of all is 6.38, showing that one star is about 356 times as bright as the other. The individual sets show an average residual of ±0.081, and the results for the different nights, ±0.065. Each reading differed only about 3° from the point where the images entirely disappeared, and a portion of the error arises from the difficulty in measuring this small angle. The circle is divided to degrees and is estimated to tenths. An error of one-tenth corresponds to a change in the result of 0.07 of a magnitude. If such small angles were ordinarily to be measured it would be better to have the circle more finely divided and moved by a tangent screw. Their effect on the final result is, however, nearly inappreciable. When smaller differences in magnitude were to be measured the results were still more accordant. Measures on the same nights of the difference in magnitude of +79° 169 and +79° 171 gave the results 3.54, 3.46, 3.48 and 3.56. The mean

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is here 3.51 and the average deviation of the individual sets is ±0.036, and of the nights ±0.040. The measures of the two fainter stars were 2.61, 2.58, 2.72 and 2.69; mean 2.65, average deviation of sets, ±0.033; of nights, ±0.055. It will be noticed that the sum of the two smaller intervals, 3.51+2.65=6.16, is slightly less than the larger interval, 6.38. This is probably due to the convergence of the rays in the cone from the object-glass, owing to which a very bright star cannot be made to entirely disappear. (See *H. C. O. Annals*, **23**, 135.) A correction, which would be insensible unless the intervals are large, might be applied if future observations confirm this source of error.

A second test of this instrument consisted in measuring the light of a variable recently found by Mrs. Fleming in the constellation Cancer. Its approximate position for 1900 is R. A. $9^h\ 40^m$; Dec. +25° 39′. It was compared on four nights with the star *B.D.*+26° 1901, mag. 7.3, which precedes it about $2^m\ 0^s.8$, and is north of it 22′.7. The measures on May 10, 11, 13 and 16, 1895, gave the magnitudes 5.04, 5.19, 5.18 and 5.31, the average deviations of the separate sets being ±0.033, ±0.043, ±0.025 and ±0.042 respectively. The variation is thus confirmed, notwithstanding its small amount during this interval. On June 12, 1895, the variable was too faint for measurement, but a comparison with a star about three-tenths of a magnitude brighter gave the interval 5.92, with an average deviation of the sets ±0.122. The variable must therefore have changed by more than a magnitude. The average deviation is larger than usual, probably owing to the extreme faintness of the star.

A third test consisted in a series of continuous observations of the variable star U Ophiuchi on the evening of June 8, 1895. This star is of the Algol type, one of its minima occurring on June 8 at $14^h.8$ G. M. T. This star was compared continuously for three hours and a half with the star *B.D.*+1°3411, which is about 36′ distant. The total number of settings was 308. The Moon was nearly full and the sky was covered with thin cirrus clouds irregularly distributed, which prevented observations with other instruments. One of the advantages of this form of pho-

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tometer, especially when the stars compared are adjacent, is that passing clouds ordinarily affect equally the brightness of both stars compared, so long as the observations are reduced to the photometric scale. This would not be the case with the scale of Argelander or other empirical scales. Even the correction for atmospheric absorption, which should always be applied if great accuracy is desired, varies with the magnitude if the photometric scale is not used. It is then difficult, if not impossible, to apply it.

The error due to passing clouds increases with the distance apart of the stars, and, perhaps, caused the large residual in the second group of observations described below. All of the observations are grouped in the following table. Each group was composed of four sets of four settings each, except the last group, which contained five sets. The Greenwich mean time is followed by the observed difference of magnitude of U Ophiuchi and *B.D.*+1°3411, the latter star being always the fainter. The third column gives the average deviation of the four sets of which each group is composed. The fourth column gives the assumed true difference in brightness found graphically, and the last column gives the residual found by subtracting the fourth column from the second.

G. M. T.	Obs. Mag.	A. D.	Curve	O.−C.	G. M. T.	Obs. Mag.	A. D.	Curve	O.−C.
$14^h\ 9^m$	0.50	.068	0.50	.00	$16^h\ 2^m$	0.89	.050	0.97	−8
14 22	0.28	.150	0.50	[−.22]	16 14	1.11	.028	1.05	+6
14 33	0.53	.028	0.50	+ 3	16 33	1.16	.050	1.16	0
14 43	0.51	.045	0.54	− 3	16 45	1.23	.018	1.22	+1
14 55	0.56	.055	0.57	− 1	16 54	1.29	.052	1.26	+3
15 9	0.70	.040	0.65	+ 5	17 1	1.34	.030	1.27	+7
15 17	0.77	.042	0.69	+ 8	17 10	1.26	.065	1.27	−1
15 35	0.86	.060	0.81	+ 5	17 21	1.22	.040	1.27	−5
15 43	0.77	.160	0.87	−10	17 29	1.20	.034	1.27	−7
15 52	0.94	.072	0.93	+ 1					

The average deviations of the individual sets is ±0.057, or, omitting the second group, ±0.052. The corresponding average deviations of the individual groups are ±0.051 and ±0.041. All of these values will be considerably diminished if we use probable errors instead of average deviations.

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In conclusion, this form of photometer may be recommended to astronomers having charge of large telescopes as a simple means of determining the brightness of the fainter stars. The star is compared directly with a brighter star without using any intermediate standard. The accidental errors are thus reduced, and since the images exactly resemble each other and may be reversed, almost all forms of systematic errors may be eliminated. Stars as faint as the fourteenth magnitude may be measured with a large telescope with all the accuracy of a brighter star, the average deviations not much exceeding a twentieth of a magnitude. The reduction is simple, and no undetermined constants are involved, the law of variation of the light depending on the fundamental principles of optics. The instrument is portable and easily removed or replaced. It is not difficult by means of it to determine the brightness of any star one to one and one-half magnitudes brighter than the limit of visibility of the telescope employed, with a computed probable error not exceeding three or four hundredths of a magnitude.

As there can be little doubt that the photometric scale of Pogson will eventually come into universal use, photometric measures of the fainter variables, comparison stars, asteroids and satellites are much to be desired.

June 13, 1895.

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FIFTIETH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1895.

BY

EDWARD C. PICKERING.

CAMBRIDGE, MASS.
PUBLISHED BY THE UNIVERSITY.
1895.

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REPORT.

To the President of the University:

Sir,—The fiftieth annual report of the Director of the Observatory is herewith presented. Several dates have been suggested any one of which may be regarded as that on which the Observatory was established. Under an agreement of November 30, 1839, with William C. Bond, the first observation at Cambridge was made by him on December 31, 1839, and he was elected Astronomical Observer on February 12, 1840. The object-glass of the 15-inch equatorial was received at Cambridge on December 4, 1846, and the mounting on June 11, 1847.

The present report seems to be a suitable place for stating briefly the past and present policy of the Observatory. The Statutes of the Observatory were prepared by President Jared Sparks, and are printed in the Annals, Volume I, page lix.

Number II states that "the objects of the Observatory are, to furnish accurate and systematic observations of the heavenly bodies for the advancement of Astronomical Science, to co-operate in Geodetical and Nautical Surveys, in Meteorological and Magnetical Investigations, to contribute to the improvement of Tables useful in Navigation, and, in general, to promote the progress of knowledge in Astronomy and the kindred sciences."

It may fairly be assumed that unrestricted gifts or bequests made to the Observatory were intended for these objects. It is noteworthy that no reference is made in the Statutes to teaching astronomy. Two principles have always been prominent in the policy of the Observatory. First, that it is primarily an institution for research. While a certain amount of teaching has been done, care has always been taken that it should not interfere with the main work of the institution. It has generally been restricted to offering students in astronomy the use of the library and instruments under suitable restrictions, and familiarizing them with the work by employing them as assistants. A second principle maintained, has been the especial advancement of the physical side of astronomy. While precise measures of position have not been neglected, the policy has been rather to undertake such studies of the physical properties of the stars as would not be likely to be made at other observatories. Under the direc-

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tion of the Bonds, father and son, the large telescope was extensively used in such work: for instance, in laying the foundation of astronomical photography, in the study of the physical appearance of the Sun and planets, of Donati's Comet, of the Great Nebula in Orion and of other nebulae and clusters. Measurements of position are represented by the first precise determinations of the position of faint stars, as those in the Nebula in Orion, and of the northern stars within one degree of the equator. The same policy was continued by Professor Winlock. The physical side of astronomy was represented by his spectroscopic work, by his photographic studies of the Sun, and by the photometric investigations contained in Volume IX of the Annals. Meanwhile his interest in measures of precision led to his procuring a meridian circle of the largest size, and taking part in the determination of the positions of the northern stars, by undertaking to observe the zone extending from $+50°$ to $+55°$. Since then the same policy has prevailed. Precedence has been given to physical work, since less attention is paid to such work elsewhere, and certain portions of our resources, as for instance the Henry Draper Memorial, are available only for such work. Accordingly much attention is paid to photography, photometry and spectroscopy. On the other hand much time and money has been spent on measurements of position, and a larger part of the unrestricted income has always been employed in this work than in any other department of the Observatory. The observations of the stars in the zone $+50°$ to $+55°$ mentioned above have been completed, and their publication, with that of the fundamental stars, fills seven volumes of the Annals containing together over two thousand quarto pages. Beside this, another zone from $-10°$ to $-14°$ has been more recently undertaken, the observations (except for the doubtful cases) have been completed, and the final reduction will be made as soon as the places of the fundamental stars can be furnished. Other investigations, like the observations of comets when too faint to be observed with small telescopes, and the search for stars having large parallaxes and proper motions, represent in all a large amount of time and money.

In pursuance of the policy named above, the public are not allowed to use the east equatorial, nor do the officers of the Observatory teach directly by lectures or otherwise. Indirectly, however, much instruction is given. Courses are given to women in connection with Radcliffe College, and the first three women to take such courses now hold positions of the first importance at other colleges. Every aid which will not interfere with the regular work of the Observatory is offered to properly qualified students in astronomy who desire to

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come to Cambridge, even to the extent, when possible, of employing them as assistants. In a word it is the policy of the Observatory to aid every department of astronomy as much as possible, giving precedence to those subjects which are less likely to be studied elsewhere.

The liberality of the friends of the Observatory has during the last few years greatly increased its opportunities for useful work, both by gifts and bequests. An attempt has been made to secure the greatest possible return in the form of scientific results, and accordingly but little has been spent on expensive fittings and furnishings or upon architectural effect. So many interesting investigations, however, have suggested themselves in recent years that it has become difficult to keep the expenses of the Observatory within its income, without abandoning a portion of the work already in progress. The west wing of the Observatory is now nearly fifty years old and is of wood. It contains the library and much valuable manuscript, the loss of which by fire would be irreparable. For about $20,000 it could be replaced by a plain brick building about sixty feet long and thirty feet wide which would closely resemble that recently erected to contain our photographic plates. The latter building has proved of the greatest convenience; its cost did not exceed the estimate; and but few changes would be made if it were to be planned again. In a few years a new building for our library and computing rooms will become a necessity. The principal of our funds cannot be used for this purpose. If the sum required is to be saved from the income, the work now in progress must be much restricted. A gift for this purpose is therefore suggested to the friends of the Observatory as a means of greatly aiding our work without an excessive expenditure.

Observatory Instruments.

East Equatorial.—A new form of polarizing photometer has been devised, and attached to this instrument (*Astrophysical Journal*, II, 89) with which any two stars brighter than the fourteenth magnitude and not more than half a degree apart may be compared. The principle is nearly the same as that of the meridian photometer, except that instead of using two objectives, the images of the stars formed by the objective of the large telescope are employed. Under favorable circumstances successive sets of four settings each give average deviations not much exceeding five hundredths of a magnitude. With this instrument 2672 settings have been made on the Algol variable, Z Herculis, 1634 settings on other stars of the Algol type,

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and 974 settings on T Andromedae. With the other polarizing photometers, 27 eclipses of Jupiter's satellites have been observed photometrically, making the total number 573. Beside these, 2908 measures have been made of variable stars of long period, 672 of β Lyrae and δ Cephei, 872 of U Cephei, and 1800 of the relative brightness of the components of double stars. 456 estimates of the brightness of variable stars of long period have been made by Argelander's method, mainly when these stars were faint. When they are brighter than the twelfth magnitude they are observed regularly with the West Equatorial, which has an aperture of six inches. 913 observations of more than one hundred variables of long period were obtained with the latter instrument. An attempt is made to follow these objects with the two instruments throughout their variations, observing them at least as often as once a month. The Transit of Mercury which occurred on November 10, 1894, and the occultation of 11 stars during the lunar eclipse of September 3, 1895, were observed with the East Equatorial. Nearly all the observations with this instrument were made by Mr. O. C. Wendell.

Meridian Circle.— The reduction of the observations made with the meridian circle by Professor William A. Rogers continues under his supervision. As stated in the last report, the observations still to be reduced are those made in the years 1880 to 1883 inclusive, and their reduction is proceeding rapidly, as the time of the only assistant employed can now be wholly devoted to this work. The last volume of the zone observations between the declinations $+49°\ 50'$ and $+55°\ 10'$ is in type except about one hundred pages.

The observations of the southern zone, between the declinations $-9°\ 50'$ and $-14°\ 10'$, made by Professor Searle in the years 1888 to 1892 inclusive, continue in course of reduction under his supervision. Early in March, 1895, the reduction had made sufficient progress to allow a short series of observations to be undertaken for the revision of the work, in order to remove uncertainties in some of the observed positions. This series occupied nine evenings during the period from March 11 to April 3 inclusive. The number of observations of fundamental stars was 53; that of circumpolar stars 20; that of zone stars 183. It is expected that a longer series of observations for revision will be begun before the end of 1895.

Meridian Photometer. — Observations have been made with the meridian photometer on 115 nights. The total number of photometric settings is 73,448. All of the observations have been made by the Director. It will be noticed that the number is unusually large, although no measures were made during the three summer

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months when the Director was absent in Europe. At this rate all the observations on which the Harvard Photometry depends could have been made in one year. The increased number is mainly due to the increased length of the evening's work, which frequently exceeded four hours. On one evening 322 stars were observed during about six hours. After its completion this series was selected for detailed examination, to see how many stars, if any, were wrongly identified, and what errors might be expected when stars were observed with this degree of rapidity. No material change has been made in the method of observation since the work was begun with this instrument in 1882, except that more material is now collected to determine with certainty the positions of the objects which have been observed. This does not diminish the chances of making an error, but renders its detection more certain. As the series mentioned above was not selected for examination until after its completion, it may be regarded as fairly representing the other work done with this instrument during the last thirteen years. The positions of the objects observed were first determined as derived from the readings of the photometer. It appeared that they differed, on the average, from the positions of the objects intended to be observed by 2′ in declination and 4′ in right ascension when reduced to the equator. This deviation, small as it is, is mainly due to the motion of the comparison star λ Ursae Minoris, and to other similar causes which in no way affect the proof of the correct identification of the star, but only the position in the field in which the stars are measured. As the diameter of the field is about 45′, the stars must in general have been brought not only into the field but must have been placed very near its centre. In 15 cases where the deviation was largest, a special examination was made for adjacent stars which might have been observed by mistake, and in every case it appeared that the object intended was that actually observed. In the case of 28 stars in this series the position of one or more adjacent stars had already been noted during previous observations of these objects and the observer's attention was called to them; and in 35 cases the identity of the object observed was rendered certain by noting on this evening the position of adjacent stars. In conclusion, it appears that of the 322 objects observed, an error of identification does not occur in a single instance. It therefore appears extremely improbable that the catalogues made with the meridian photometer are sensibly affected by errors of identification. An examination was next made of the average deviation of the results of these observations from those derived from all the observations of the same stars. In

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226 cases the observations were completed, and it appears that the average deviation of the results expressed in magnitudes was ± 0.098. The positive sign prevailed, showing that the stars in this series were observed on the average about one-sixteenth of a magnitude too faint. Applying a correction for this, the average deviation is reduced to ± 0.073. A careful watch is always kept for clouds, the observer looking for them from an adjacent balcony every ten minutes to assure himself that none are present, and after each star observed when clouds are approaching the meridian. During the series mentioned above, clouds were looked for 30 times.

Another test was made to see if the accuracy of the individual settings could be materially increased by making them more deliberately. From the average results of three evenings it appeared that the average deviation of single settings was ± 0.12 when nine seconds was spent upon each setting. This is about the usual time occupied in regular observations. A similar determination was made when the average time of each setting was twenty-nine seconds, the observer attempting to make the most accurate settings possible. The average deviation of the results, however, was found to be ± 0.12, or exactly the same as before. Each star is observed on at least two evenings, four settings being made each evening. If the average error of the final result is ± 0.10, it follows that it would only be reduced to ± 0.09 if the errors of setting could be reduced to zero. When greater accuracy is required, the error in the final result is much better reduced by the policy hitherto adopted of increasing the number of evenings on which each star is observed rather than devoting more time to each setting. This is because the real errors to be apprehended are those due to unequal transparency of different portions of our atmosphere, and to similar causes which can only be counteracted by increasing the number of nights on which each star is observed.

The revision of the stars in the Harvard Photometry has been completed, and the observations are now in form for publication except for any correction which it may be desirable to apply to the individual series. The observation of all the stars of the magnitude 7.5 and brighter and in declination between $-40°$ and $+20°$ have also in general been completed, except between 14 and 20 hours of right ascension.

A comparison has been made of the magnitudes of the series of 100 standard stars as derived from the first of these catalogues with their corresponding magnitudes as given in the Harvard Photometry, and in Volume XXIII of the Annals. From this it appears that the results

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differ in the three catalogues from their mean, by ± 0.035, ± 0.026 and ± 0.023, and that the greatest differences for any one star are 0.14, 0.11 and 0.13 respectively. No systematic differences dependent on magnitude exceeding three one hundredths of a magnitude are perceptible for stars from the second to the sixth magnitude. Since the mean epochs of the three catalogues are 1881, 1885 and 1893, an unexpected permanency both in the instruments and in the brightness of the stars themselves is thus indicated.

Henry Draper Memorial.

The number of photographs taken with the 8-inch Draper telescope is 2056. The number taken in Peru with the 8-inch Bache telescope is 2469. With these two instruments an attempt is made to obtain photographic charts of the entire sky from the north to the south pole at least once every year, showing all stars brighter than the thirteenth magnitude. Only about four hundred plates are required, with exposures of ten minutes. All of the spectra photographed with these instruments have been examined as usual by Mrs. Fleming. As a result a large number of objects having peculiar spectra have been detected. Among them are 20 new variable stars which have been found from the presence of bright hydrogen lines in their spectra, and confirmed by an examination of the photographic charts of the same regions. Five stars have been found whose spectra are of the fourth type, three of the fifth type, three new gaseous nebulae, two stars in which the hydrogen line $H\beta$ is bright and three in which the spectra are peculiar. A well marked meteor trail appeared on one of the plates. Besides these, two new variable stars have been found by Miss L. D. Wells and one by Miss E. F. Leland. The latter star is of interest because its period appears to be much longer than that of any other variable star hitherto discovered. The hydrogen lines have been shown to be bright in the photographic spectra of the known variables, S Cassiopeiae, R Arietis, R Persei and T Hydrae, while the spectrum of T Camelopardali is of the fourth type.

The number of photographs taken with the 11-inch Draper telescope is 251. They include 50 images of the spectrum of β Aurigae, 30 of them showing the lines double. The lines are double in 25 out of 160 photographs of the spectrum of ζ Ursae Majoris. The latter star was photographed nearly every clear night, since the law determining the time at which the lines are double has not yet been discovered. An attachment has been made to this telescope by which it can be moved in declination about 25″ at intervals of exactly one minute,

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and double this amount every ten minutes. Photographs have thus been obtained, showing the variations from minute to minute of U Cephei and other stars of the Algol type. A similar arrangement has permitted photographs to be taken of the satellites of Jupiter while undergoing eclipse. Professor Edwin B. Frost of Dartmouth College has expressed an interest in the spectrum of β Lyrae, and has kindly undertaken the study of our photographs of this object, all of which, to the number of 107, have been lent him. This example suggests the possibility of greatly increasing the usefulness of all the photographs taken here. We should be glad to lend in the same way many more of our photographs, if we could place them in equally efficient hands. Many astronomers are so situated that they could discuss photographs which they have not the opportunity of taking themselves. This applies with especial force to photographs of objects in the southern sky. Many of these photographs we already have and others could be taken as required. We could thus place in the hands of astronomers material which they could otherwise obtain only by large expenditures of time and money. As examples of such work may be mentioned positions, distribution and brightness of stars in clusters, distribution of light in spectra, peculiar spectra, eclipses of Jupiter's satellites, and lunar mountains. Correspondence is invited with any astronomers who would like to take up such investigations. Our collection of photographs affords a means of determining with certainty, the variability of stars in any part of the sky. Several astronomers have availed themselves of these facilities to determine the variation, if any, of suspected objects.

Boyden Department.

The political troubles in Peru at one time seriously endangered the Boyden Station. While the better classes in all parties would doubtless offer every protection, there is always danger from a lawless soldiery. Professor Bailey and his family were in a train which was captured near Mollendo, and at the time Arequipa was taken, there was much firing within hearing of the station. While the government would doubtless make good any pecuniary loss which might be sustained, it is much to be desired that nothing should occur to mar the friendly feelings to the Observatory now shown by all classes of Peruvians. These feelings were doubtless much strengthened by the friendly visit of President Pierola to the Arequipa station last April.

The number of photographs taken with the 13-inch Boyden telescope is 1205. Some of these represent the spectra of the brighter

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stars, some are designed to determine the parallaxes of various peculiar objects, and some furnish excellent charts of the principal clusters both in the northern and southern heavens. An examination of the latter by Professor Bailey has led to the interesting result, that large numbers of variable stars occur in certain star clusters while few, if any, have been found from a similar examination of other clusters. Forty-six variable stars have been found in the cluster N. G. C. 5904 and eighty-seven in the cluster N. G. C. 5272.

The great need of the station is a telescope of large size and an observer who can devote his time exclusively to visual observations. The opportunities for useful work are exceptionally great: first, on account of the almost unrivalled atmospheric conditions; and secondly, owing to the comparatively little attention hitherto paid to the southern stars. No large refracting telescope has ever been used in the southern hemisphere, or even south of latitude 35° north.

A line of meteorological stations established by this Observatory is now in operation from the coast across the Andes to the valley of the Amazon. They include Mollendo (altitude 100), La Joya (4150), Arequipa (8060), Alto de los Huesos (13,300), Mt. Blanc Station on the Misti (15,600), El Misti (19,200), Cuzco (11,000) and Santa Ana (3,000).

The Bruce Photographic Telescope.

A clause was inserted in the contract for the Bruce telescope to the effect that the final payment shall be made when the instrument is mounted at the Observatory and gives as good star charts as the parties of the first part (Messrs. Alvan Clark & Sons) can effect. Accordingly the final payment was made last spring, on the assurance of Mr. Clark that the last of these conditions had been fulfilled. Professor Bailey came to Cambridge last summer to superintend the removal of the Bruce telescope to Peru, but unfortunately he was recalled suddenly by illness in his family. He was able, however, to spend much time on the instrument and obtained results which lead to the belief that satisfactory photographs will eventually be obtained. The principal changes required are a better driving clock, and one in which the intervals at which it is controlled are shorter, a stiffer fork carrying the telescope, and better illumination for the wires. A second prism has been constructed for the Bruce telescope. It is of crown glass and has a small angle so that the dispersion is small. It is expected that stars having peculiar spectra can thus be detected even if they are extremely faint.

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As stated in previous reports, a large piece of work is in progress to determine the photographic brightness of the stars upon a uniform scale. This work consists of three parts: First, 334 plates have been taken with the transit photometer. A duplicate instrument has been constructed with which similar photographs may be taken at Arequipa. Secondly, 281 plates have been taken, on which the images of the stars are out of focus, so that they may be measured as surfaces instead of points. On 63 of these plates 5102 stars have been identified. The brightness of 690 stars has been measured on seven plates. Thirdly, 108 plates have been taken, on which 2700 stars of about the tenth magnitude, and 3941 brighter stars for comparison, have been selected and measured, one in each square degree.

Miscellaneous.

Library.—The library of the Observatory has been increased during the year by the addition of 293 volumes and 1189 pamphlets. Moreover, 106 volumes and 424 pamphlets, mostly relating to meteorology, have been deposited in it by the Library of Harvard College. Not including the latter, the total numbers of volumes and pamphlets in the library of the Observatory on October 1, 1895, were therefore 8109 and 11,602 respectively.

As the station at Arequipa, Peru, will be maintained permanently, it is desirable, owing to its remoteness, that it should have a library of its own. Copies of astronomical and meteorological works sent there direct, or through this Observatory, will be gratefully received and will prove of much value.

Telegraphic Announcements.— The distribution of telegraphic announcements of discovery has been continued as in past years. Astronomers are requested to continue to send to this Observatory announcements of their discoveries for transmission to the observatories of Europe and America.

Buildings and Grounds.— The widening of Concord Avenue, which was still under discussion at the time of the last report, is not now apprehended, as the project, fortunately for the Observatory, has been abandoned. Electric cars have been substituted for horse-cars upon that Avenue, but observations upon the collimators of the meridian circle, made during the passage of the cars, show that they have no noticeable effect in disturbing the pier.

Exhibition of Photographs.—A part of the photographs exhibited at Chicago and afterwards at San Francisco, as stated in former

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reports, were sent this year to a photographic exhibition conducted by the Imperial Institute of London. Another portion of the photographic collection has more recently been sent to Atlanta, Georgia, to be shown at the exhibition now in progress there.

Publications.—The printing of Volume XXXII, Part I, of the Annals of the Observatory, containing a discussion of photographic and visual observations by Professor W. H. Pickering was completed and the volume was distributed early in the year. Volume XXXIV, containing observations by Professor Bailey of the brightness of 7922 southern stars, is wholly in type. Volume XXXVI which will complete the journal of the zone observations made by Professor Rogers, is in course of publication, and 199 pages have been printed, while about 100 pages still remain. Volume XL, Part IV, containing the Blue Hill Meteorological Observations for 1894, is largely in type. Volume XLI, Part III, containing a summary of observations made by the New England Weather Service in 1893, is in progress.

The preparation for the press of Volume XXVI, Part II, has made much progress, and that of Volume XXX, Part IV, is complete. The first relates to the work of the Draper Memorial, and the second to the study of the clouds at the Blue Hill Observatory.

A plate representing the Harvard College Station at Arequipa, with explanatory text, appeared in the American Meteorological Journal, XI, 146; and an account of the meteorograph intended for the station on the summit of El Misti, by its constructor, Mr. S. P. Fergusson, appeared in the same Journal, XII, 116.

The following publications have also appeared during the year: —

Forty-ninth Annual Report of the Director of the Astronomical Observatory of Harvard College. Cambridge, 1894.

Observations of β Persei with the Meridian Circle of Harvard College Observatory. By A. Searle. *Astronomical Journal*, xv, 54.

On the Forms of the Disks of Jupiter's Satellites. By S. I. Bailey. *Astrophysical Journal*, ii, 97.

The Harvard College Meteorological Stations in Peru. By S. I. Bailey. *American Meteorological Journal*, xi, 76.

Stars having Peculiar Spectra. By M. Fleming. *Astronomische Nachrichten*, cxxxvii, 71.

Stars having Peculiar Spectra. Eleven New Variable Stars. By M. Fleming. *Ibid.* cxxxviii. 175. *Astrophysical Journal*, i, 411.

Photographic Observations of Eclipses of Jupiter's Satellites. By Willard P. Gerrish. *Ibid.* i, 146.

Comparison of Photometric Magnitudes of the Stars. By E. C. Pickering. *Astronomische Nachrichten*, cxxxvii, 65.

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Observations of the Transit of Mercury, 1894, Nov. 10. By E. C. Pickering. *Ibid.* cxxxvii, 69.

Discovery of Variable Stars from their Photographic Spectra. By E. C. Pickering. *Astrophysical Journal*, i, 27.

Comparison of Photometric Magnitudes of the Stars. By E. C. Pickering. *Ibid.* i, 154.

T Andromedae. By E. C. Pickering. *Ibid.* i, 305.

Eclipse of Jupiter's Fourth Satellite, February 19, 1895. By E. C. Pickering. *Ibid.* i, 309.

A New Form of Stellar Photometer. By E. C. Pickering. *Ibid.* ii, 89.

EDWARD C. PICKERING, *Director.*

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Reprinted from THE ASTROPHYSICAL JOURNAL for October, 1895

SEVEN NEW VARIABLE STARS.

M. FLEMING.

CHICAGO
The University of Chicago Press
1895

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SEVEN NEW VARIABLE STARS.[1]

By M. FLEMING.

SINCE the discovery of eleven new variable stars at this Observatory was communicated to THE ASTROPHYSICAL JOURNAL in a letter dated April 9, 1895, seven other variables have been discovered here. Five of them were found in the examination of the photographs of stellar spectra taken at Cambridge and at the Arequipa Station in Peru, forming part of the work of the Henry Draper Memorial. These stars have spectra of the third type, having also the hydrogen lines bright. This peculiarity led to their being suspected of variability, since many known variable stars of long period possess this class of spectrum. Two were found from a comparison of the photographic chart plates with the maps of the *Durchmusterung*, while selecting and checking the selection of the faint stars for standards of stellar magnitudes. The variables are enumerated in the following table which gives the constellation, the designation, the approximate right ascension and declination for 1900, the catalogue magnitude of the star and the magnitudes when brightest and when faintest, as derived from the photographs:

Constellation	Designation	R. A. 1900	Dec. 1900	Mag.	Mag. Br.	Mag. Ft.
Eridanus....	*C.D.M.* −24° 1960	$3^h\ 51^m.0$	−24° 20′	8.6	7.2	11.0
Orion.....	*B.D.* +0 939	5 0 .2	+ 1 2	6.0	8.8	10.6
Puppis.....	*Z.C.* 7^h 3056	7 42 .6	−41 57	9½	9.8	12.1
Cancer	.....	9 4 .0	+25 39	—	9.6	<13.5
Hydra.....	*S.D.* − 7° 2873	9 37 .7	− 7 38	9.0	9.7	10.6
Libra.....	*S.D.* −14° 4228	15 27 .7	−14 59	9.4	8.5	<12.3
Ursa Minor..	.....	15 33 .3	+78 58	- -	8.4	11.4

— Eridani. *C.D.M.* −24° 1960. The magnitudes of this star as derived from photographs taken on September 6, October 20,

[1] Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

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November 6, 1889; September 13, 1890; January 30, February 1, October 22, December 17, 1891; December 14, 1892; November 18, November 20, 1893; August 13, August 14, September 22, October 27, November 6, November 10, November 16, and December 13, 1894, are 9.8, 7.2, 7.7; 9.1; 9.9, 9.8?, 9.0, 7.9; <9.8; 9.8, 9.6; 8.4, 8.3, 8.0, <8.4, 9.4, 9.8, 9.8, and 11.0 respectively.

—Orionis. *B.D.*+0°939. The variation in the light of this star was discovered by Miss E. F. Leland. It presents an especial interest on account of the apparent length of its period. It was bright in 1879 and again in 1891, and faint in the intermediate years. As, however, all the observations were made at about the same part of the year further observations are required, as it is still possible that the period may be a little less or a little greater than one year. Of the variability there can be no doubt. While it is proved by the photographs, the visual observations alone are sufficient to establish it. Thus four of the excellent Potsdam observations give the results 6.08, 5.99, 5.87, and 6.38. No one who looked at it last winter could doubt that it was fainter than the sixth magnitude. In fact the meridian photometer on six nights gives the results 7.10, 7.23, 7.02, 7.22, 7.13, and 7.22. In 1880 the meridian photometer gives its magnitude as 5.8; in 1881, 6.7; in 1882, 6.8; in 1883, 6.6; in 1885, 6.8; in 1894, 6.8; and in 1895, 7.2. Its magnitudes as derived from photographs taken on November 9, 1885; February 29, September 28, 1888; December 29, 1890; January 26, January 26, December 11, December 11, 1891; January 4, January 8, January 21, December 20, December 22, December 28, December 29, 1892; September 20, October 2, and November 26, 1893 are 10.0; 9.8, 9.6; 9.0; 8.9, 8.8, 10.0, 10.0; 9.8, 9.5, 9.6, 10.3, 10.4, 10.2, 10.3; 10.6, 10.4, and 10.1 respectively.

—Puppis. *Z.C.* 7^h 3056. *C.D.M.* −41° 3363. The magnitudes of this star as derived from photographs taken on October 3, October 22, November 13, 1889; September 27, September 27, October 24, October 24, October 26, October 26, 1893; April 18, October 19, and November 24, 1894 are < 10.6, < 10.8, 9.8;

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11.8, 12.1, 10.4, 10.0, 10.0, 9.9; 10.8, 10.7, and 9.9 respectively.

—Cancri. R.A. $9^h\ 4^m.0$; Dec. $+25°\ 39'$. The magnitudes of this star as derived from photographs taken on December 6, 1889; December 7, December 9, December 14, December 18, December 29, 1890; March 26, 1891; February 15, March 7, April 9, 1892; March 12, March 18, March 31, April 5, November 22, 1893; January 2, January 25, March 30, November 15, 1894; January 23, March 5, May 9, and May 23, 1895, are 11.5; 10.2, 10.2, 10.4, 10.7, 10.7; 11.6; 12.2, 12.8, <13.5; 11.9, 12.3, <12.0, <12.1, 10.6; 9.6, 10.0, 12.0, 11.8; 9.8, 10.0, 12,0, and <12.1 respectively.

—Sextantis. *S.D.* $-7°2873$. The variation in the light of this star was discovered by Miss L. D. Wells. Its magnitude as derived from photographs taken on January 24, April 9, 1888; December 9, 1889; March 25, 1891; February 15, March 6, March, 14, March 30, 1892; February 24, March 15, November 22, 1893; April 19, December 17, 1894; February 11, February 13, April 10, April 10, April 11, April 11, April 11, April 16, April 16, April 17, April 17, April 18, April 18, April 20, April 23, April 23, April 25, April 25, May 1, May 1, May 2, May 3, May 3, May 6, May 7, May 7, May 9, and May 23, 1895 are 9.8, 9.8; 10.4; 10.6; 9.9, 9.8, 9.9, 9.8; 9.9, 9.9, 9.9; 10.0, 9.9; 9.8, 9.7, 9.9, 10.1, 9.7, 9.9, 9.9, 9.9, 9.9, 9.9, 9.9, 9.9, 9.9, 10.2, 10.0, 9.9, 10.1, 10.0, 10.0, 10.0, 10.2, 10.3, 10.2, 10.2, 9.9, 10.2, 10.4, and 10.4 respectively. These results were confirmed by measures made by Mr. O. C. Wendell with a polarization photometer attached to the 15-inch equatorial.

—Libræ. *S.D.* $-14°\ 4228$. The magnitudes of this star as derived from photographs taken on February 28, May 17, 1888; July 18, 1890; May 16, May 16, June 3, June 23, June 23, 1891; May 10, May 10, May 10, May 11, 1892; May 7, May 7, July 22, July 27, 1893; May 13, June 14, June 17, June 18, and June 20, 1895 are <12.3, 10.8; <11.4; <11.8, <11.0, <11.5, <11.8, <11.9; <10.8, <10.6, <10.4, <8.9; <11.8, <11.7, 10.6, 10.7; 8.9, 8.5, 8.5, 8.6, and 8.7 respectively.

—Ursæ Minoris. R.A. $15^h\ 33^m.3$; Dec. $+78°\ 58'$. The mag-

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nitudes of this star as derived from photographs taken on March 9, August 28, September 29, October 1, November 10, 1890; July 16, 1891; April 11, 1892; August 15, August 15, August 26, 1893; August 17, October 17, November 10, November 12, November 12, December 29, 1894; January 1, January 2, April 23, April 25, May 1, May 2, May 3, May 6, May 7, May 16, May 22, May 23, May 29, June 7, June 14, June 17, and June 18, 1895 are 11.4, 8.4, 8.6, 8.4, 9.3; 8.4; 9.3; 9.8, 9.8, 10.3; 11.2, 11.3, 10.6, 10.7, 10.5, 8.9; 8.9, 8.8, 9.2, 9.4, 9.4, 9.2, 9.03, 9.4, 9.4, 9.4, 9.8, 9.7, 10.0, 10.2, 10.4, 10.4 and 10.4 respectively.

The photographs of the above variables have been examined, and the variability of the stars confirmed by Professor E. C. Pickering.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., July 5, 1895.

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Stars Having Peculiar Spectra

M. FLEMING

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STARS HAVING PECULIAR SPECTRA.

EIGHT NEW VARIABLE STARS IN CETUS, VELA, CENTAURUS, LUPUS, SCORPIO, AQUILA AND PEGASUS.[1]

By M. FLEMING.

AN examination of the Draper Memorial photographs received during the past summer from the Arequipa Station has added several stars to the lists of those already known to have peculiar spectra. The objects are contained in the following table, which gives the designation of the star, the approximate right ascension and declination for 1900, the catalogue magnitude and a brief description of the photographic spectrum.

Designation	R. A. 1900	Dec. 1900	Magnitude	Description
B. D.—1° 2312	$9^h\ 45^m.9$	$-1°\ 33'$	8.9	Type IV
Z. C. 13^h 717	13 13 .4	−73 55	8½	Type IV
A. G. C. 19416	14 15 .7	−49 24	8½	Type IV
Z. C. 17^h 921	17 15 .3	−41 39	8½	Peculiar
....	18 7 .8	−19 5	...	Type V
C. D. M.—30° 15469	18 9 .7	−30 54	10	Type V

—Lupi. *A.G.C.* 19416. In using the photographic chart plates to identify this fourth type star, Miss L. D. Wells discovered distinct evidence of its variability. A further examination of photographic charts taken on May 24, June 13, June 13, July 2, July 4, July 9, July 9, 1889; April 20, May 22, May 28, 1890; May 21, May 21, May 27, May 27, 1891; May 14, May 16, May 18, August 10, August 13, 1892; April 28, April 28, May 1, May 10, May 15, June 3, June 23, June 23, June 26, 1893; April 14, April 14, May 21, May 22, July 26, 1894; March 12, March 12, April 8, April 15, and April 16, 1895, gave the magnitudes 11.2, 10.9, 11.2, 11.2, <9.9, 11.2, 11.2; <8.7, 10.9, 11.1; 10.9, 10.9,

[1] Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

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11.0, 11.2; 11.2, 10.6, <10.4, <10.0, <9.9; 10.8, 11.0, 10.6, <9.6, <10.0, 11.1, 10.8, 11.0, 11.2; 10.8, 10.6, 10.6, 10.8, 9.6?; 10.3, 10.4, 10.4, 9.2, and 9.8 respectively, thus confirming the variability of this star.

C. D. M. −30° 15469. The presence of the bright lines $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$, and $H\zeta$ in the photographic spectrum of this star was discovered by Professor James E. Keeler, at this Observatory, on October 18, 1895. This star is of interest since its photographic spectrum closely resembles that of η Carinae.

In addition to the objects described above, six stars having spectra of the third type, and also bright hydrogen lines, have been proved to be variable. The following table contains the constellation, designation, approximate right ascension and declination for 1900, the number of plates examined and the maximum and minimum magnitude as derived from the photographs.

Constellation	Designation	R. A. 1900	Dec. 1900	No. Plates	Magnitude Max.	Min.
Vela	*C.D.M.*−41° 6787	11h 44m.1	−41° 12′	27	7.8	12.4
Centaurus	*Z. C.* 11h 3351	11 50 .0	−58 42	55	8.6	13.0
Centaurus	*A. G. C.* 19643	14 25 .1	−29 39	26	7.7	8.8
Scorpio	.....	17 8 .3	−33 19	68	9.4	14.1
Aquila	.....	19 53 .7	− 8 10	52	10.0	<12.4
Pegasus	*B. D.* +5° 4928	21 56 .1	+ 5 39	41	8.2	<13.0

—Velorum. *C.D.M.* −41° 6787 The magnitudes of this star, as derived from photographs taken on May 25, June 1, June 13, 1889; April 1, May 11, May 14, May 25, May 28, 1890; June 23, July 2, July 3, 1892; April 28, May 1, May 1, May 5, May 8, June 27, June 27, 1893; April 9, May 19, June 18, June 18, 1894; Feb. 20, April 26, May 1, May 21 and June 4, 1895, are 8.1, 7.8, 8.4; 8.2, <8.9, 8.4, 9.2, 9.1; <9.6, <9.6, <9.6; 12.4, <11.9, 12.4, <10.2, <9.8, 11.2, 11.2; 11.6, 11.2, 9.7, 9.6; <10.4, <9.4, 9.3, 9.2, and 8.2 respectively.

—Centauri. *Z. C.* 11h 3351. The magnitudes of this star, as derived from photographs taken on May 20, May 27, May 31, June 13, June 13, 1889; April 3, April 13, May 5, May 9, May 26, 1890; May 3, 1891; March 18, August 5, August 7, August

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12, 1892; January 13, January 13, January 13, February 25, April 6, April 28, May 2, May 2, May 2, May 2, May 4, May 4, May 4, May 4, May 12, May 16, May 20, June 22, June 26, June 26, 1893; April 17, May 15, May 15, May 17, May 23, June 1, June 1, June 1, June 1, 1894; March 26, April 3, April 3, April 10, April 11, April 14, April 21, May 9, June 4, June 14, and June 15, 1895, are 9.2, 9.5, 10.0, 10.9, 10.8; <11.3, <9.0, 11.5, 11.4, 10.2; <9.1; 10.2, <8.6, <9.8, <9.8; <9.7, <11.6, <11.4, <9.0, 8.6, 10.7, 10.8, 10.9, 10.9, 11.0, 10.8, <10.9, 11.0, 11.0, <9.7, <10.6, 11.3, <11.9, 12.4, 12.6; 10.8, 9.4, 9.5, 9.5, <9.1, 9.8, 9.8, 9.8, 9.8; <10.8, <11.7, <12.2, 13.0, 12.9, <10.4, <10.4, 11.4, 9.6, 9.2, and 8.8 respectively.

—Centauri. *A. G. C.* 19643. The magnitudes of this star, as derived from photographs taken on June 3, June 13, June 13, June 21, June 25, July 1, August 1, 1889; April 14, May 13, May 15, May 29, June 7, June 23, 1890; May 27, June 27, 1891; April 23, April 23, 1892; May 31, June 3, June 3, June 5, 1893; June 19, July 5, July 6, 1894; March 12 and April 19, 1895, are 8.8, 8.3, 8.4, 8.7, <7.8, 7.7, 8.1; 8.4, <8.6, <8.7, 8.2, 8.2, 8.2; 8.8, 8.0; 7.8, 7.8; 8.0, 8.2, 8.1, 8.2; 7.9, 8.1, 8.0; 8.8 and 8.8 respectively.

—Scorpii. R. A. $17^h\,8^m.3$; Dec. $-33°\ 19'$. The magnitudes of this star, as derived from photographs taken on June 4, June 27, July 3, July 5, July 13, July 13, 1889; March 25, May 9, May 9, May 10, June 7, June 14, June 21, June 23, September 5, September 6, 1890; May 18, May 18, May 20, May 29, August 3, August 19, 1891; May 17, May 17, June 13, August 10, August 22, October 6, 1892; April 27, April 28, May 7, June 8, June 16, June 16, June 23, July 6, July 6, August 1, 1893; April 26, May 2, May 2, May 14, May 23, May 24, June 14, August 14, August 31, 1894; April 6, April 6, April 29, May 11, May 11, May 11, May 23, June 1, June 1, June 1, June 3, June 14, July 1, July 1, July 1, July 1, July 8, July 8, July 18, August 3, and August 3, 1895, are <9.2, <9.3, 13.4, 13.5, <13.4, <12.9; 11.0, <10.3, <9.8, <9.4, 12.2, 12.2, 12.8, 12.5, 14.1, <13.1; 11.6, 11.6, 11.5, <10.5, <9.2, <9.3; 10.6, 10.6, 11.4, <10.3, <9.7, <12.4; 11.4, 11.3,

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11.2, <10.5, <9.4, <10.3, 11.6, <9.2, <10.5, <12.1; 12.1, <11.8, <9.3, 11.5, 11.4, <10.3, 11.4, 12.4, <10.4; <13.4, <13.3, <9.6, 10.3, 10.3, 10.4, 9.8, 9.4, 9.5, 9.6, 9.4, 9.7, 9.9, 9.8, 9.9, 9.8, 10.3, 10.1, 10.4, 10.6, and 10.7 respectively.

—Aquilae. R. A. $19^h\ 53^m.7$; Dec. $-8°\ 10'$. The magnitudes of this star, as derived from photographs taken on November 3, November 7, 1888; August 3, August 4, August 30, September 19, 1890; May 17, May 19, June 2, June 2, June 5, August 1, August 19, September 10, 1891; April 3, May 17, May 17, June 29, July 27, August 19, August 23, September 6, September 12, September 16, September 18, September 26, September 27, 1892; July 21, July 22, July 22, August 3, August 4, August 10, August 15, August 17, September 2, September 13, September 20, October 20, October 20, 1893; June 8, June 13, June 14, August 18, August 28, October 15, November 1, 1894; May 24, June 1, June 3, June 4, and June 11, 1895, are 10.6, 10.8; <11.2, <10.5, <11.1, <8.9; <11.6, <10.9, <10.5, <11.1; <9.2, <10.7, <10.6, <11.1; <10.5, <12.4, <11.6, <8.7, <11.7, <9.2, <9.1, <11.6, <11.0, <11.1, <9.2, <11.2, <12.1; <12.3, <12.3, <11.0, <11.2, <11.5, <11.3, <9.8, <9.2, 11.9, <11.5, 11.8, <12.2, <11.1; <9.6, <11.3, <10.1, <11.0, <10.3, <10.7, <9.1; 10.1, 10.0, 10.0, 10.0, and 10.2, respectively.

— Pegasi. *B. D.* $+5°$ 4928. The magnitudes of this star, as derived from photographs taken on November 18, 1889; June 30, August 25, 1890; June 13, June 13, June 19, August 1, August 24, September 4, September 20, October 1, October 3, October 8, October 14, October 16, October 20, October 21, 1891; September 7, September 8, September 10, September 11, September 18, September 27, September 29, September 30, October 8, October 10, October 13, October 22, 1892; July 24, August 17, September 20, September 29, September 29, October 25, November 2, 1893; May 21, October 5, November 13, November 16, 1894; and June 1, 1895, are <12.8; 9.0, 12.2; 12.0, 12.2, 12.4, <11.4, <10.5, <12.0, <11.6, <11.0, <9.2, <10.9, <13.0, <12.6, 12.8, <11.0; <12.8, <12.9, <13.0, <12.4, <13.0, <12.7, <12.5, 12.8, <11.8, <12.1, 11.8?, 11.8;

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<12.1, <10.1, <10.2, <9.7, <9.6, 10.0, 10.0; <13.0, <8.5, 12.8, <12.5; and 8.2, respectively.

In the Wolsingham Observatory Circular, No. 42, issued July 15, 1895, the Rev. T. E. Espin announces the probable variability of a star in R. A. $19^h\ 52^m.4$; Dec. $-2°\ 11'$ (1900). On September 13, 1895, a star nearly in this position was discovered independently here, by means of its photographic spectrum, and its variability confirmed from photographic plates. The magnitudes of this star, as derived from photographs taken on August 23, October 18, 1888; August 4, August 5, August 30, September 30, 1890; May 19, May 19, June 2, June 2, September 2, September 17, 1891; April 3, May 17, May 17, June 29, August 23, September 1, September 5, September 18, September 27, 1892; July 20, July 20, July 20, July 21, July 21, August 10, August 10, August 15, August 15, September 2, October 2, October 9, October 20, October 20, 1893; June 29, July 21, August 10, 1894; May 24, and July 2, 1895, are <12.2, 9.8; <11.6, <11.7, <12.2, 12.1?; <9.4, <12.0, <11.5, <11.2, <10.9, <11.9; 9.2, 9.9, 10.1, <8.7, <8.9, <12.3, <11.2, <9.2, <12.2; <11.7, <10.4, <11.2, 11.8, 11.8, <10.9, <10.1, <9.7, <10.2, <10.9, <9.8, <11.3, <11.9, <12.2; 10.9, 11.2, 11.6; 8.4, and 8.6, respectively.

— Cetus. *B. D.* $-1°\ 475$. The variability of this star, whose approximate position for 1900 is in R. A. $3^h\ 14^m.3$; Dec. $-1°\ 26'$, was discovered by Miss L. D. Wells, from a comparison of photographic charts. The magnitudes, as derived from photographs taken on September 6, October 17, 1888; December 19, December 23, 1889; January 4, January 9, January 14, December 28, 1890; March 11, September 17, September 17, September 20, November 25, December 1, December 8, December 10, December 18, 1891; January 5, October 5, December 16, December 23, December 24, December 28, 1892; September 17, September 20, September 20, October 4, October 5, October 6, November 10, November 26, 1893; January 23, July 16, August 16, November 16, November 16, 1894; January 19, August 6, and October 10, 1895, are <10.4, 11.6; 9.8, 9.6; 10.0, 9.7, 9.9, 10.1; <10.5, 10.8,

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10.6, 11.0, <10.6, <10.6, 10.4, 10.2, 10.0; 9.7, 11.4, 11.7?, 10.3, 11.7?, 10.2; 10.2, 10.0, 10.4, <10.3, <10.4, <10.0, <9.9, <12.5; 9.7, 9.9, 9.3, 12.2, 12.3; 9.6, 9.4, and 12.4, respectively.

In the ASTROPHYSICAL JOURNAL, **2**, 198, the star *S. D.* $-7°$ 2873, in the table, is given in the constellation Hydra (following Heis). The constellation should be Sextans, as given in the notes, p. 200.

November 19, 1895.

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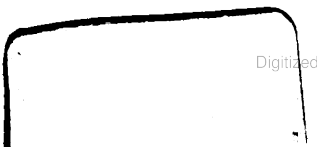

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